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CONCEPTUAL DESIGN OF SINGLE TURBOFAN ENGINE POWERED LIGHT AIRCRAFT

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CESSNA AIRCRAFT COMPANY

PAWNEE DIVISION

WICHITA, KANSAS

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REPORT DATE: 31 March, 1977

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CONCEPTUAL DESIGN OF SINGLE TURBOFAN ENGINE POWERED LIGHT AIRCRAFT

By Michael Newman and George L. Huggins

31 March 1977

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Prepared under Contract No. NAS2-9243
Cessna Aircraft Co.
Pawnee Division
Wichita, Kansas

for

AMES RESEARCH CENTER

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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SYMBOLS

AR	Aspect ratio
$\bar{a}_G$	Average acceleration during takeoff ground run
$\bar{a}_T$	Average acceleration during transition from liftoff to steady state climb
a_1, a_2, a_3, a_4	Constants in weight trend equation
b_W	Wing span
C_D	Drag coefficient
C_{D_o}	Parasite drag coefficient
C_{D_i}	Induced drag coefficient
$C_{D_{GE}}$	Drag coefficient in ground effect
$C_{f_{equiv}}$	Equivalent friction coefficient
C_L	Lift coefficient
$C_{L_{MAX}}$	Maximum lift coefficient
$\bar{c}_W$	Mean geometric chord of wing
$\bar{c}_H$	Mean geometric chord of stabilizer
$\bar{c}_V$	Mean geometric chord of vertical
c_l	Section lift coefficient
$c_{l_{max}}$	Section maximum lift coefficient
e	Oswald efficiency factor
f	Equivalent flat plate area
g	Acceleration due to gravity

h_f	Maximum depth of fuselage
k_1, k_2	Constants in weight equation
L	Lift
l_f	Length of fuselage
l_H	Horizontal tail arm (.25 $\bar{c}_W$ to .25 $\bar{c}_H$)
l_V	Vertical tail arm (.25 $\bar{c}_W$ to .25 $\bar{c}_V$)
M	Mach number
n'	Design load factor
R	Reynolds number
S_G	Ground distance covered during takeoff ground run
S_T	Ground distance covered during transition from liftoff to steady state climb
S_C	Ground distance covered during climb from end of transition to 50 ft. above runway
S_H	Horizontal tail area
S_V	Vertical tail area
S_W	Wing area
S_{wet}	Wetted area of complete aircraft
T4/T2	Engine temperature ratio (proportional to throttle settings)
$T_{V_{AVG}}$	Thrust, during takeoff, at the average velocity for the takeoff segment being calculated
$T_{V_{50}}$	Thrust, during takeoff, at the climb speed, $V_{50}=1.2V_{Stall}$
t/c	Airfoil thickness ratio (subscripts r-root, t-tip, avg-average)

V	Speed
V_{LOF}	Lift off speed
V_W	Wind speed
V_{50}	Climb out speed over 50 ft. obstacle
V_S	Stall speed
$\overline{V}_H$	Horizontal tail volume coefficient
$\overline{V}_V$	Vertical tail volume coefficient
W	Takeoff gross weight
W_W	Wing weight
W_{fus}	Fuselage weight
W_{pp}	Powerplant weight
W_n	Nacelle weight
W_H	Horizontal tail weight
W_V	Vertical tail weight
W_{mg}	Main gear weight
W_{ng}	Nose gear weight
W_c	Control system weight
W_e	Equipment weight
W_f	Furnishings weight
W_{id}	Inlet duct weight
W_{tp}	Tailpipe weight

$\overline{W}$	Dry empty weight minus engines, props, avionics, battery, alternator, and regulator
w_f	Maximum width of fuselage
Δx	Center of gravity range (ie aft cg limit minus fwd cg limit)
λ	Taper ratio
μ	Rolling friction coefficient
ϕ	Slope of runway
ρ	Air density
γ	Climb angle

ABBREVIATIONS

avg	Average
BEW	Basic Empty Weight - DEW plus optional equipment and all liquids except useable fuel
DEW	Dry Empty Weight
DOC	Direct Operating Cost
Garrett	Refers to AiResearch Manufacturing Company of Arizona, a division of The Garrett Corporation
GASP	General Aviation Synthesis Program
LFL	Landing Field Length
LSE	Light Single Engine
MGC	Mean Geometric Chord (same as $\overline{c}_w$)
SLS or SLST	Sea Level Static Thrust
TOFL	Takeoff Field Length

1.0 ABSTRACT

This report presents the results of a study by Cessna Aircraft Co. in which the NASA developed General Aviation Synthesis Program (GASP) was evaluated as to its usefulness as a design tool. This evaluation was accomplished by:

1) Appraising the results of CR 137944 which were obtained by the Garrett Corp. using the GASP,

2) conducting a conceptual study of a Cessna designed turbofan aircraft using Cessna's sizing routines and the GASP and

3) comparing the GASP methodology to the design procedures now in use by Cessna.

This evaluation concluded that the GASP needs extensive modifications to fulfill its purpose; but once these are made the program could be a useful new tool for general aviation.

As a corollary to this evaluation the practicality of using turbofans as powerplants for general aviation single engine aircraft was investigated. The conclusion is that they will be practical if and when large reductions in the cost and fuel consumption of small turbofans are achieved.

2.0 INTRODUCTION

This report presents the results of a study by Cessna Aircraft Co. under NASA contract NAS2-9243 sponsored by the Ames Research Center. The purposes of the study were:

1) To determine the validity of the results obtained by AiResearch Manufacturing Company of Arizona (Division of Garrett Corp.) using the General Aviation Synthesis Program (GASP) in the design of a light turbofan powered general aviation class airplane. (Ref. 1)

2) To conduct a preliminary design of a similar aircraft based on Cessna experience and analyzed both by GASP and by methods currently in use by Cessna.

3) To evaluate the usefulness of the GASP as a design tool and compare the methodology of this program to the design procedures now in use by Cessna. Further, to recommend modifications of the GASP to increase its usefulness.

4) To identify research that must be done before the turbofan engine can be utilized effectively on light, single engine general aviation aircraft.

In NASA-Ames RFP2-26167, (Ref. 4) which initiated this study, the contractor was required to choose only one of the aircraft types considered in Ref. 1 for analysis. However, in an effort to make this design exercise conform to actual design practices, Cessna chose to investigate both a 2-place trainer and a 4-place utility aircraft. The approach was to allow minor compromises in the design of each in order to maximize commonality between them. This is standard practice when initiating a new line of aircraft. Otherwise, introduction of additional new models is needlessly expensive.

A market analysis was conducted to determine the design specifications for both of these planes. Additional considerations that influenced the design of Cessna's baseline configuration were aesthetics, crashworthiness, safety of operation, allowance for configuration growth, and low technical risk to minimize development time, effort and cost.

The turbofan engine data was supplied by NASA as specified by the contract. Several difficulties, however, were encountered. First, the installation losses, included in the data, were determined for a podded engine installation such as shown in Ref. 1 (see Fig. 28). However, the Cessna design incorporated a buried engine (see Fig. 12), for which the installation losses were expected to be significantly different. Based on a Cessna analysis and with the concurrence of NASA, an additional 6 percent penalty in thrust was charged against the supplied engine data to account for this installation. It is of course recognized that the Garrett engine would require redesign to match the engine nozzle characteristics to the duct design.

Second, the Cessna design methodology required a larger range of throttle settings than were supplied in the engine data. Further, Cessna found a need

for data to Mach numbers slightly above .3. Only for the engine sized for Garrett's 2-place plane were data at these Mach numbers supplied. It was possible to extrapolate the 2-place engine data for the necessary throttle settings but it was not possible to extrapolate the 4-place engine data to the required Mach numbers. These data could not be supplied to Cessna in time for this plane to be evaluated. Therefore, the 4-place design was not sized for its mission. The effect of dropping the 4-place design is minimal. In all particulars, except size, it would have duplicated the 2-place airplane. The procedures followed in the design would not have changed nor would the data trends that resulted. When the design was compromised to allow stretching the 2-place aircraft to the 4-place configuration, the major objective of choosing to look at both planes was achieved.

The basic criterion used by Cessna for sizing these aircraft was minimum DOC. This of course required a knowledge of engine price. By NASA decision, this was set at $25/lb. of SLS thrust.

No effort was made to evaluate the approach and landing performance of this design. The engine characteristics supplied to Cessna were for an engine optimized for a different installation. Therefore, the flight idle characteristics (ill defined even for the engine supplied) could not reasonably be used to evaluate the approach flight path characteristics of the Cessna design. There is no reason to believe that the landing requirements would be constraining on this design.

3.0 DISCUSSION

3.1 PHASE I - MARKET ANALYSIS

3.1.1 Design Requirements

The design requirements, incorporated in the Garrett design study, laid down in Ref. 4 and shown in Table 1, are neither adequate to define the airplane nor completely realistic. Therefore, Cessna undertook a study to define a new set of design requirements.

This study took the form of a comparison of the performance parameters of present day aircraft in the 2-place trainer and 4-place LSE categories. These comparisons are shown on Fig.'s 1 and 2.

The planes shown in the comparison were chosen since, from their acceptance, it is felt that they most ideally meet the market for which they are aimed.

The parameters shown (take-off field length, stall speed, etc.) were adjudged to be the most important. However, it should be noted that they are not all equally constraining on the design of the aircraft.

Based on these graphs and on the experience of the Cessna design personnel, the requirements in Table 2 were derived.

The range requirements for these aircraft were developed from considerations of endurance and cruise speed. It is felt that 3.5 hrs is a comfortable flight time for the 2-place aircraft designed for the training role but used in the transportation mode. For the 4-place utility aircraft four hours flight time was considered comfortable. The design range for each aircraft is determined for these flight times at the cruise speed for maximum range.

Cruise speed is not chosen but is one of the design parameters that are varied to maximize the range while minimizing DOC.

The cruise altitude was set higher than the typical reciprocating engine powered aircraft to take advantage of the jet's lower power lapse rate with altitude and the inherently higher true airspeeds available.

It is imperative that a trainer be able to fly and land without flaps. Landing is almost always the most difficult lesson for the student to grasp. Therefore, it is essential that the procedures be kept as simple as possible. If the wings are optimized for cruise and the landing performance is obtained with a powerful flap system using large deflections, then the flaps become necessary for the landing. The speed spread with flaps becomes large and the flying qualities vary significantly from flaps up to flaps down. Furthermore, once set for landing, it is then necessary to at least partially retract the flaps in order to execute a go-around. Although students are trained to manage the flaps, it is desirable that early solo

flights be made with little if any flaps and that mismanagement not result in an unrecoverable incident. Otherwise, the potential for a student making a mistake is too great to tolerate. The flaps up stall speed must, therefore, be set at a reasonable level. Thus, stall speed directly impacts on the wing design rather than indirectly through the flap configuration. As a corollary, this philosophy results in a simple flap system, a plane that can be configured such that it handles well during a crosswind landing, and a plane that is flexible enough to perform adequately a variety of missions in addition to the basic training function.

Garrett, in Ref. 1, set the take-off field length at 2000 ft. Cessna feels that this is excessively long. Many airports, presently open to trainers could not be used by a plane with this field length. Therefore, a field length of 1700 ft. on a hot day (90°F) was chosen.

TABLE 1

GARRETT DESIGN CONCEPTS

Design Requirements	2-Seat Trainer	4-Seat Utility
Design Payload (lbs)	400	600
Maximum Payload (lbs)	400	800
Design Cruise Speed (mph)	125	150
Design Cruise Altitude (ft)	7500	10000
Design Range (s.m.)	400	550

Important Design Features of the Garrett Conceptual Designs

Single Turbofan Engine

NASA GA(W)-1 Wing Airfoil Section

Full Span Fowler Flaps

Spoilers for Lateral Control

High Aspect Ratio Wing

Conventional Materials and Structural Design

Fixed Landing Gear

Standard Equipment Weight Includes Dual Controls and IFR Instruments and Avionics

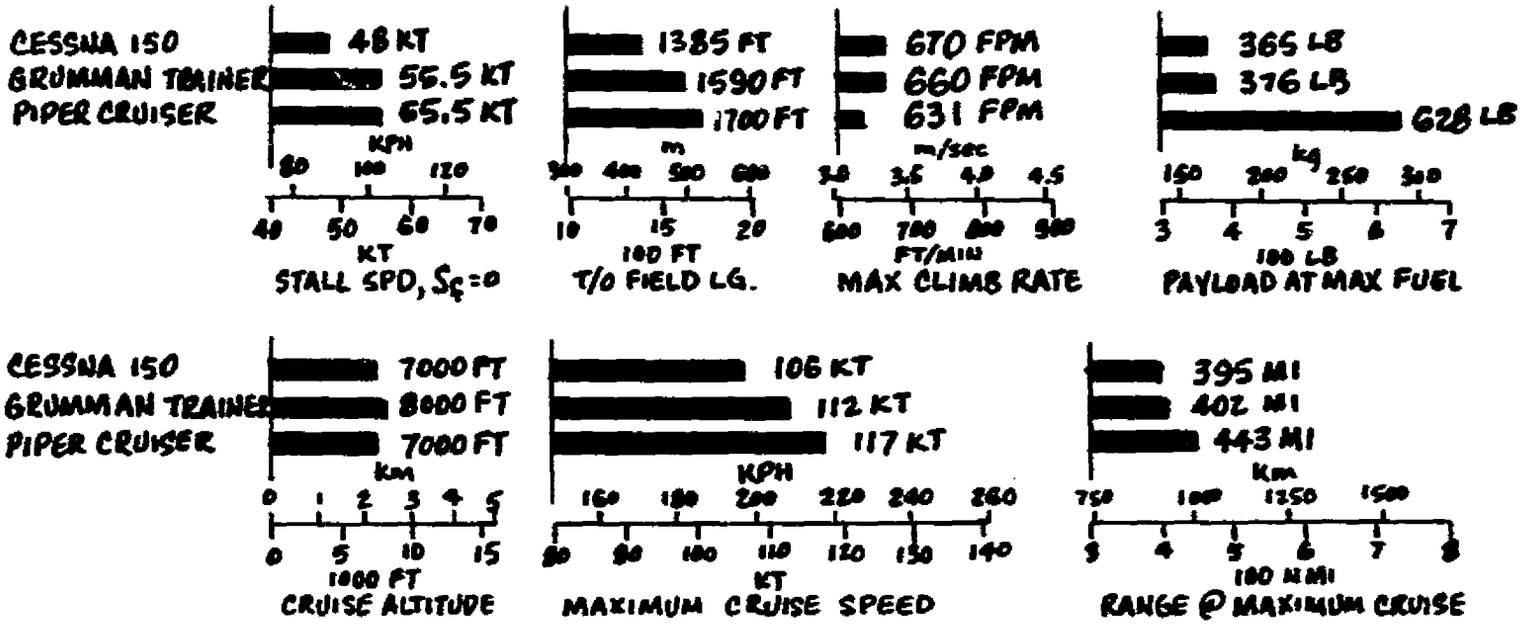

Figure 1. Comparison of Performance Parameters of Present Day Aircraft. 2-Place Trainers.

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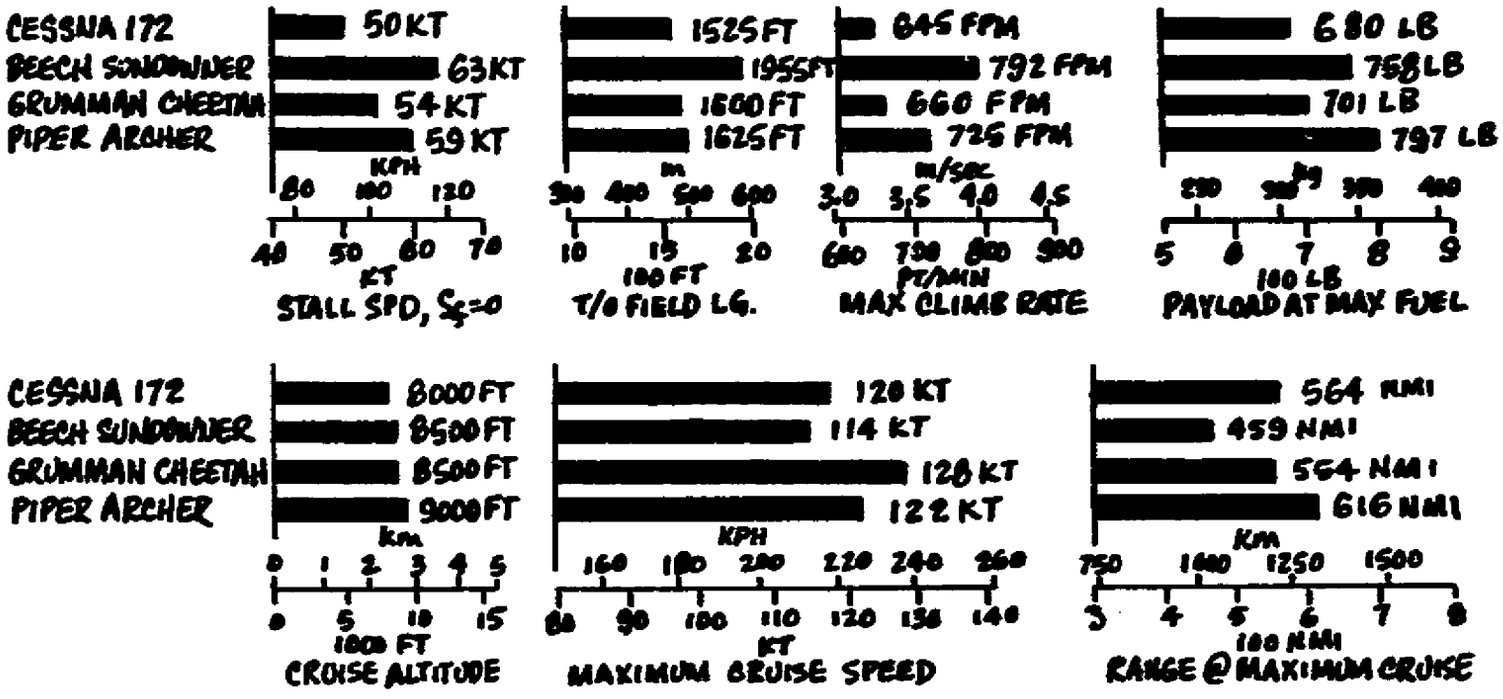

Figure 2. Comparison of Performance Parameters of Present Day Aircraft. 4-Place LSE.

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TABLE 2

SINGLE TURBOFAN ENGINE POWERED LIGHT AIRCRAFT

Contract NAS2-9243

Design Requirements

2-Place Trainer

Payload (including optional equipment*)	400 lb.
Endurance (no reserves)	3½ hrs. (to be re-evaluated if tip tanks are necessary to hold the required fuel volume)
Cruise Altitude	10,000 ft.
Takeoff Field Length to 50 ft. (S.L.@90°F)	1700 ft.
Stall Speed (δ_f=0)	50 Kts.

4-Place Utility

Payload (including optional equipment*)	800 lb.
Endurance (no reserves)	4 hrs. (to be re-evaluated if tip tanks are necessary to hold the required fuel volume)
Cruise Altitude	10,000 ft.
Takeoff Field Length to 50 ft. (S.L.@90°F)	1700 ft.
Stall Speed (δ_f=0)	55 Kts.

Service ceiling, cruise speed and landing field length are not expected to be constraining on the design. They will, of course, be monitored to make certain that the resulting values are realistic.

* NAVCOM and Transponder

3.1.2 Costing Methodology

3.1.2.1 Direct Operating Cost

Direct operating costs for Cessna advanced design purposes are determined by summing the following cost item estimates:

1) Engine periodic maintenance
2) Engine overhaul
3) Airframe maintenance
4) Hull insurance
5) Liability insurance
6) Fuel
7) Oil
8) Depreciation

Item #1 is estimated using a formula derived from data obtained on small business jets; it is a function of the maintenance labor rate, the engine thrust, the price, the range, and the block speed. No data on Garrett engines were available for an engine maintenance correlation. Garrett felt that engine maintenance costs would be negligible. However, it seems more reasonable to base the estimate on the engine maintenance costs of other small business jets.

Engine overhaul cost is estimated to be 37.6% of the engine cost, this is based on data for the P & W JT-15D used on the Citation.

Item #3 is estimated using a linear fit to airframe maintenance cost for several general aviation airplanes; it is a function of dry empty weight less engines, props, avionics, battery, alternator, and regulator and is shown in Fig. 3.

Item #4 is based on hull insurance rates for all Cessna models, and is a function of airplane price and utilization. It is for noncommercial use with a qualified pilot.

Liability insurance rates are, again, based on those for existing Cessna models, and are a function of the number of places and the utilization. This empirical data was used without any attempt to bias it to the special rates charged for planes involved in student training. Since the 2-place plane will find broader application than just being a trainer, it was felt that the normal rates were appropriate.

Item #6 is based on a fuel cost of $.70/gal. The depreciation period of the aircraft is 7.5 years. The DOC, as quoted in this report, is based on a utilization rate of 300 hrs/yr.

The DOC equations are shown in Appendix 1.

3.1.2.2 Airplane Price

In order to compute the airplane price the airframe price must be esti-

mated and summed with the prices of the following items: engines, avionics, battery, alternators, and regulators. Airframe price is estimated using a formula derived from a correlation of all Cessna single engine airframe prices, and shown in Fig. 4. Engine price for this study has been dictated by NASA to $25.00 per pound of sea level static thrust. Avionics, battery, alternator, and regulator prices are for those used on the Cessna 150 Commuter II. Avionics cost is an item that is not amenable to correlation with other factors (such as aircraft price). The price is calculated from an itemized list of specific equipment, taken to be that typically installed in aircraft similar to the design configuration. In the case of the baseline, this was chosen, because of its popularity, to be that equipment installed in the Commuter II version of the Cessna 150. (Early in the study this list was originally taken from the Cardinal II. When emphasis was shifted to the 2-place trainer, the weight and cost estimates were revised to reflect the avionics of the Commuter II.) The avionics costs are shown below based on 1976 retail prices.

Item	Commuter II	Cardinal II (w/NAV PAC)
Basic Avionics Kit	175	410
Antenna and Coupler	55	-
300 Nav Com (360 Channel)	1895	1895
300 Nav Com (720 Channel)	2295	2295
300 ADF	-	1595
300 Transponder	645	645
	5065	6840

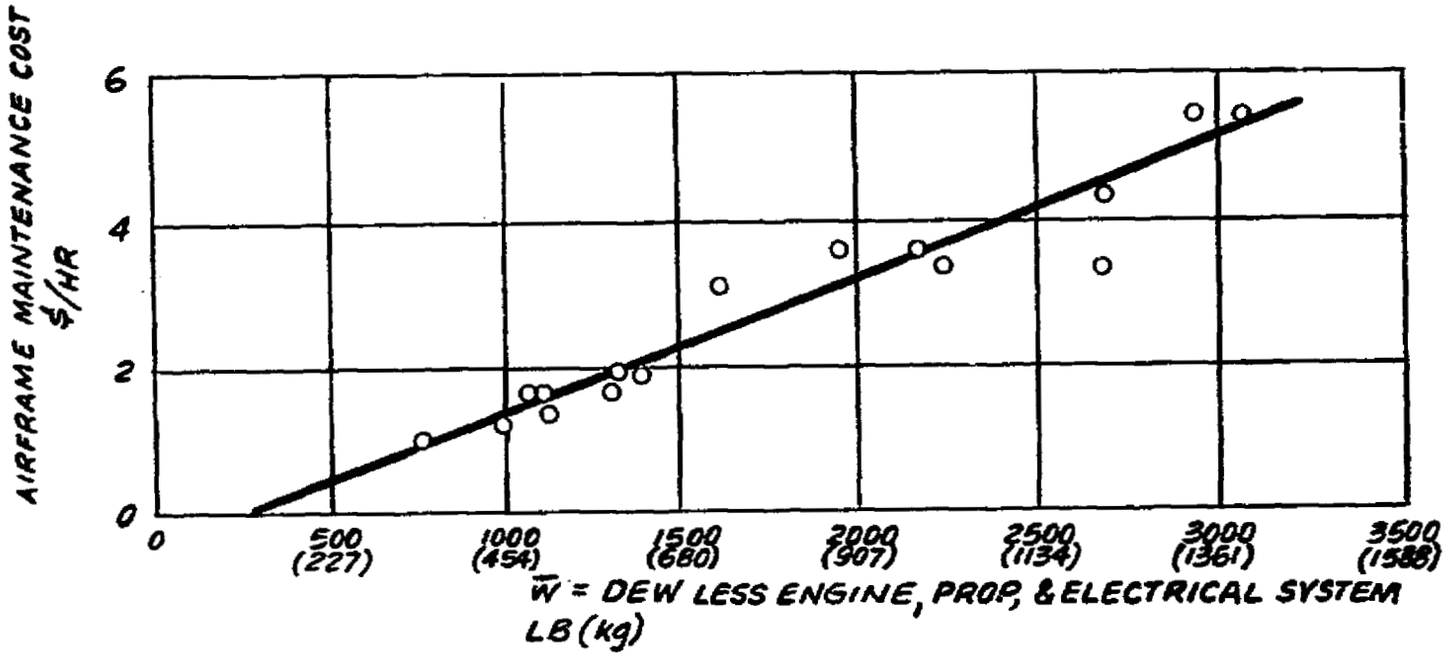


Figure 3. Airframe Maintenance Cost

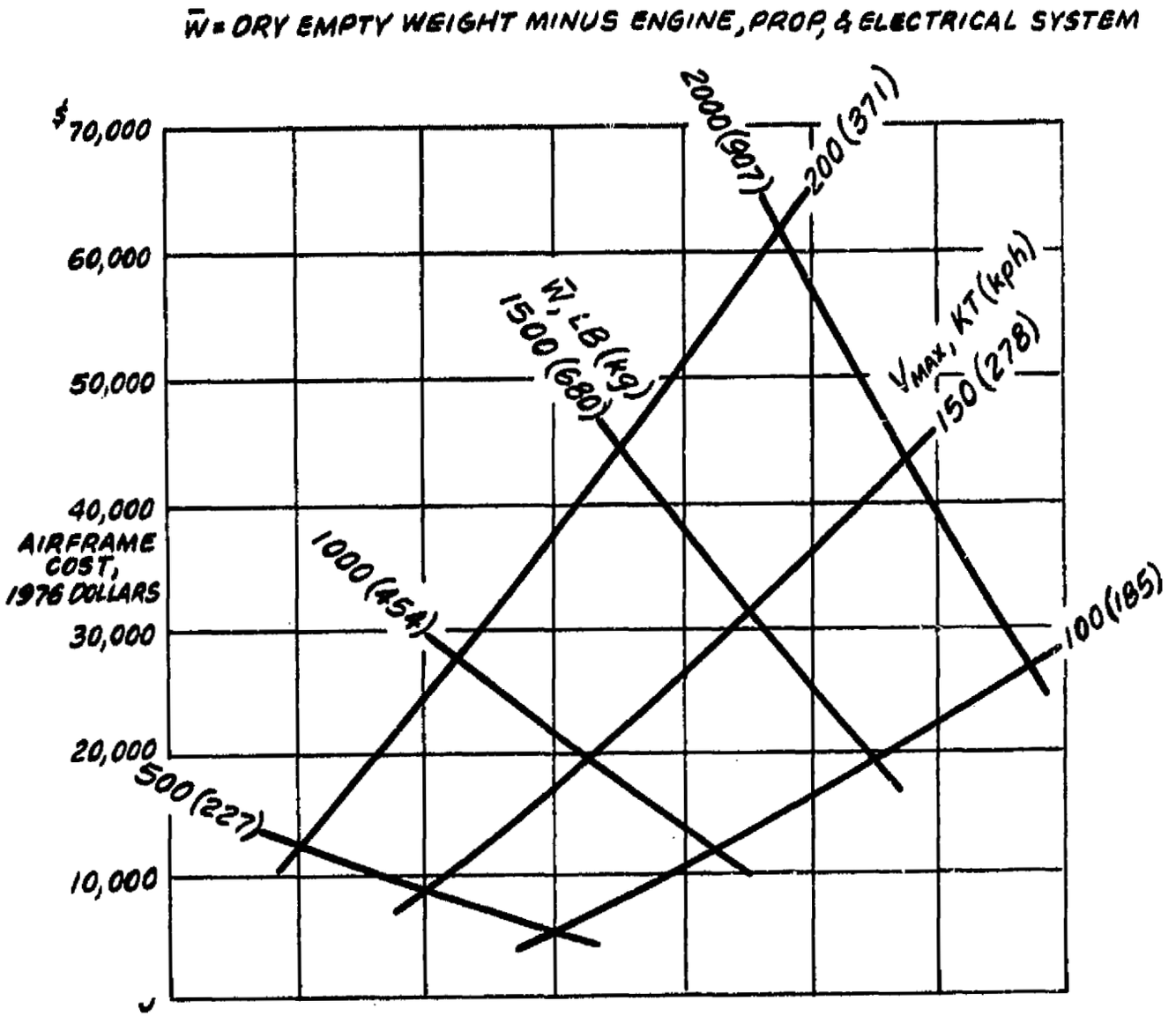


Figure 4. Airframe Cost

3.2 PHASE II - BASELINE DEFINITION

3.2.1 Configuration Layout

3.2.1.1 Design Considerations

As in all conceptual design layouts the configuration of Cessna's design for a light turbofan powered general aviation aircraft involved several compromises. The first of these was whether to try an unconventional design in an effort to improve the general aviation state-of-the-art in aircraft design or to pursue a conventional layout. Several unconventional designs are shown on Fig. 5. These have potential for reducing aircraft weight and increasing performance. However, the following must also be considered:

1) Unusual Flying Qualities - In the case of the tailless designs the landing attitude would of necessity be high and it would be difficult to incorporate flaps; therefore, these designs would not be adequate for the trainer application. In fact, the flying qualities of a tailless aircraft are so different that a pilot trained to fly in one would require further training to fly a conventional configuration.

In the case of the canard, the interference between a canard and the wing can cause very poor handling qualities, especially near the stall, unless the wing and canard are very carefully designed and tailored to each other. Further, the tip mounted verticals are subject to large yaw-roll coupling of control inputs. The complexity of these design tasks and risks are hard to overstate and the design cost can be expected to be high.

2) Development Costs - For each of these designs new technology will probably be needed in the avionics area. Such technology does not presently exist for the manufacturer of general aviation aircraft. This will be reflected in high development costs and increased aircraft price.

3) Market Acceptability - Unlike the military or space markets, where performance is everything, the general aviation market must cater to the desires of the consumer. As the automobile industry has proven over and over, this market is not open to radical changes in styling and design. Rather, it responds best to slow evolutionary changes.

4) Purpose of Contract - The very purpose of this study was to compare the GASP to the Cessna design methods. Since these methods are calibrated against conventional designs, they are inadequate to handle such radically different concepts and the credibility of the desired GASP critique would be questionable. For these reasons, the unconventional designs were not pursued.

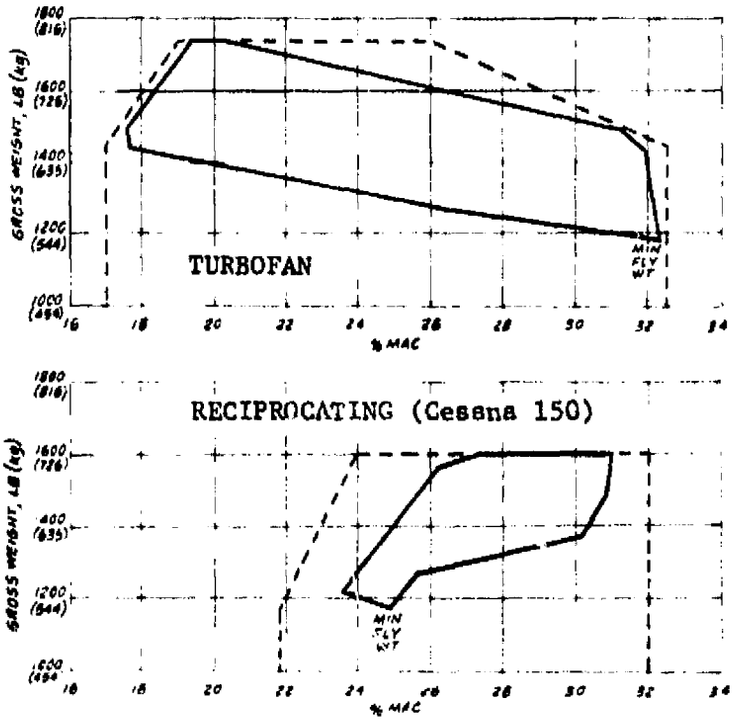
For the conventional design (i.e. horizontal, vertical tails behind the wing mounted on fuselage or boom, conventional cabin, etc.) three main decisions were confronted:

1) Wing Location - high, mid or low. This decision must consider the

effects of the location on visibility, empennage and aft fuselage design, gear (size, design and attachment to wing or fuselage) and engine location (inlet routing, outlet design, and interference with main spar design).

2) Engine location - the decision on where to place the engine must account for the impact on center of gravity travel, power induced trim changes, high velocity-high temperature exhaust flow fields and on marketing considerations of aesthetics.

With reciprocating powered aircraft, the engine weight is used to balance the tail and aft fuselage weight. This allows the payload to be located around the wing-body neutral point which in turn minimizes the center of gravity shift between heavy and light loading. With the jet, however, the powerplan must be located aft of the wing (or podded on the wing) to avoid excessively long exhaust ducts. Therefore, the payload is the only weight left to place ahead of the wing to balance the tail, fuselage, and engine and there is a large c.g. shift between heavy and light payloads. This is of particular concern in the trainer where the student first learns to fly with the instructor aboard; which means the plane is at its forward c.g. On the first solo, however, with the instructor out, the student is faced for the first time with an aft c.g. condition. It is, therefore, imperative that the engine be located as close to the wing-body neutral point as possible in order to minimize this effect. The effect of engine placement on c.g. travel can be illustrated by comparing the estimated loading of the turbofan powered trainer to that of the Cessna 150. This is shown in Sketch (a) below. Note that the turbofan loading is all forward of the minimum flying weight while the loading of the 150 can be either forward or aft of the minimum flying weight depending on placement of the optional equipment.



Sketch (a)

The engine can be neither too high nor too low without inducing unacceptable trim changes with power application. The flow characteristics of a jet must be considered, including the necessity to provide a good inlet system and a good exhaust path. Further, the designer must ensure that the air entrained into the exhaust does not induce large changes in the local flow angles at the tail which is seen by the pilot as a trim change with thrust.

Finally, the installation must not make the plane look ungainly. Good aesthetics are essential for a successful product.

3) Inlet location and type - the choice of inlet design and location must consider flow characteristics, installation losses, safety and aesthetics.

The inlet location should not necessitate too long an inlet duct length or be of such a design that the dynamic pressure recovery is poor. In the case of bifurcated inlets, consideration must be given to their characteristics in sideslip.

The inlet must also not be placed where unstable flow off a stalled airplane wing will be ingested. This is particularly true for the trainer where power off and on stalls are done as a matter of routine. The engine must not be rendered inoperative due to flow irregularities at the inlet.

The inlet should not be located such that its suction effect constitutes a danger to the passengers when entering or exiting the plane. Neither should it be located where there is a great probability of ingesting runway debris which would damage the engine.

In light of the three design considerations discussed above, many possible configurations were drawn. These are shown in Fig. 6, 7, and 8. For one or more of the reasons stated above, these designs were narrowed down to the 4 shown in Fig. 9. Of these, the bifurcated inlet design was eliminated for safety reasons and because of the difficulty in design of the inlet system. The overhead mounted engine was eliminated on the basis of the thrust trim change and the poor aesthetics.

From the final two designs the nose inlet was eliminated due to the inlet duct passing through the cabin. The importance of considering both the 2 and 4 place designs can be seen very clearly here. For either airplane it would be possible to duct the flow through the cabin; but, since the duct diameter and diffuser design are usually optimized for a given engine, neither duct could be used on the other plane without incurring penalties in drag or engine performance. Therefore, this design was incapable of being stretched in an efficient manner. If for no other reason, this design would be rejected because of the unnecessary expenses associated with a lack of commonality between models.

Design Concepts

UNCONVENTIONAL CONFIGURATIONS

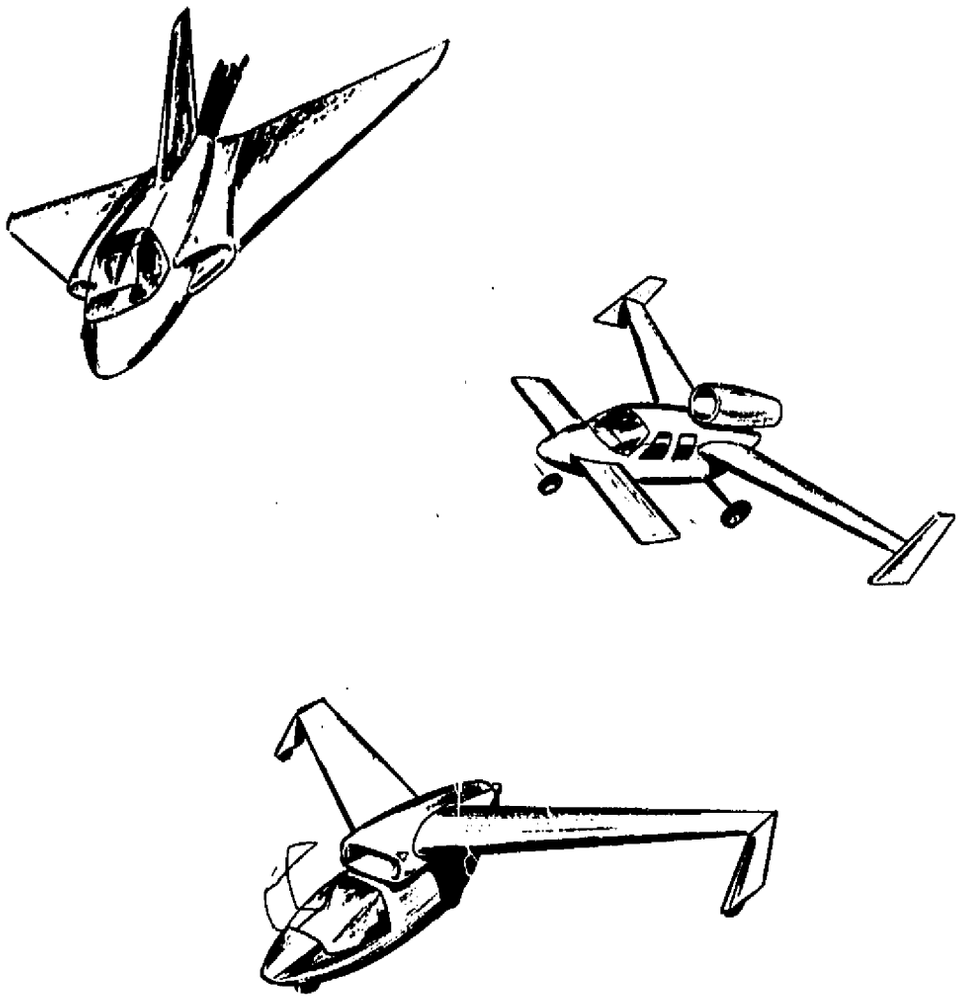


Figure 5. Design Concepts. Unconventional Configurations.

Design Concepts

SIDE-INLET DESIGNS

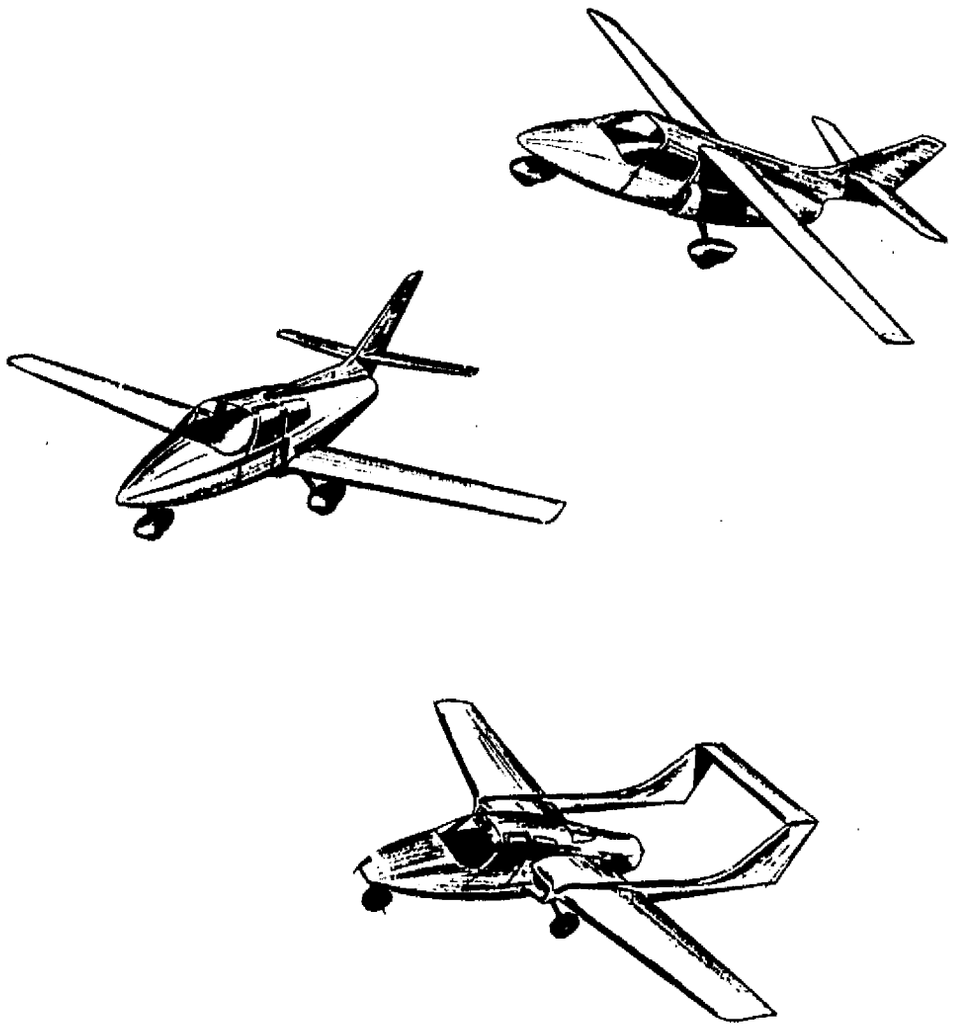


Figure 6. Design Concepts. Configurations Featuring Side Inlets.

Design Concepts

NOSE-INLET DESIGNS

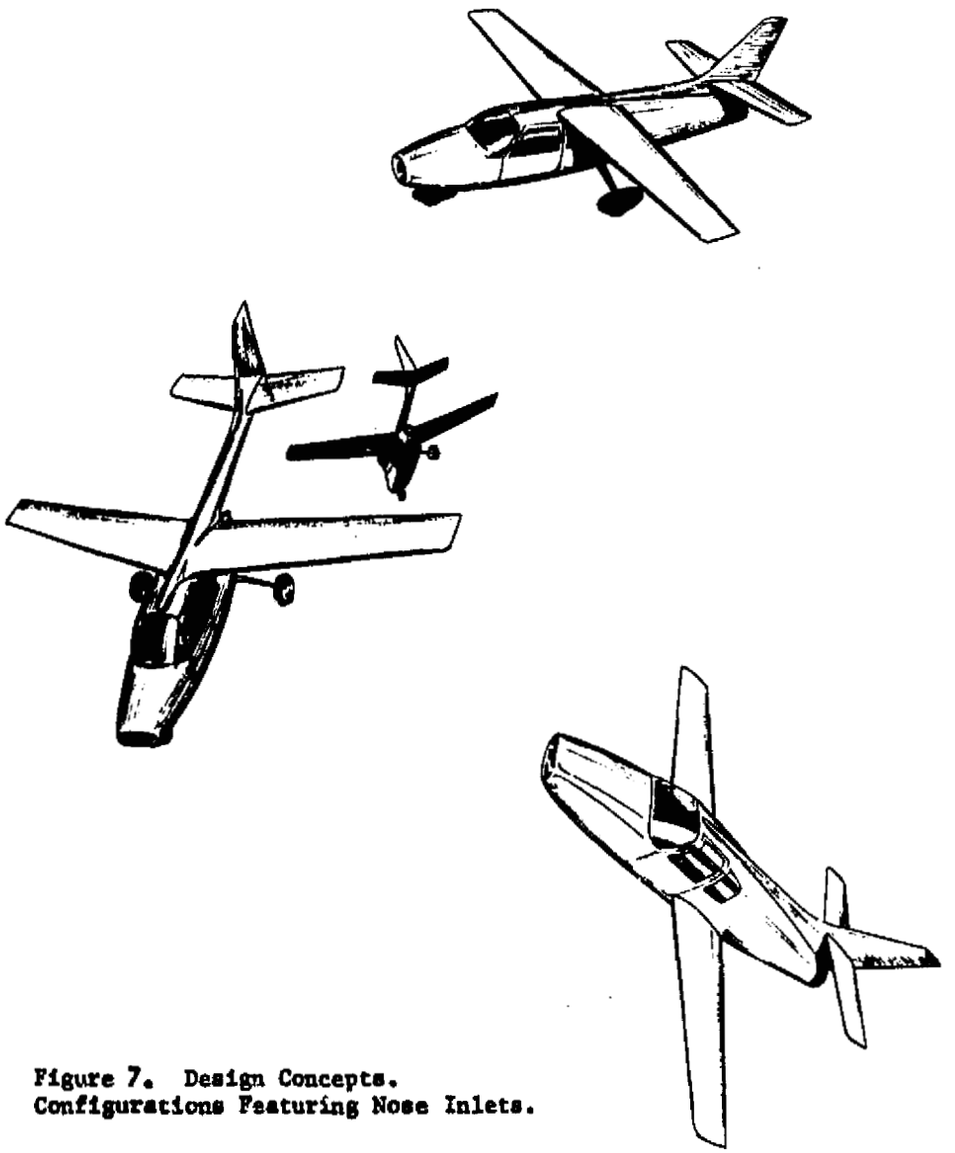


Figure 7. Design Concepts.
Configurations Featuring Nose Inlets.

Design Concepts

OVERHEAD-INLET DESIGNS

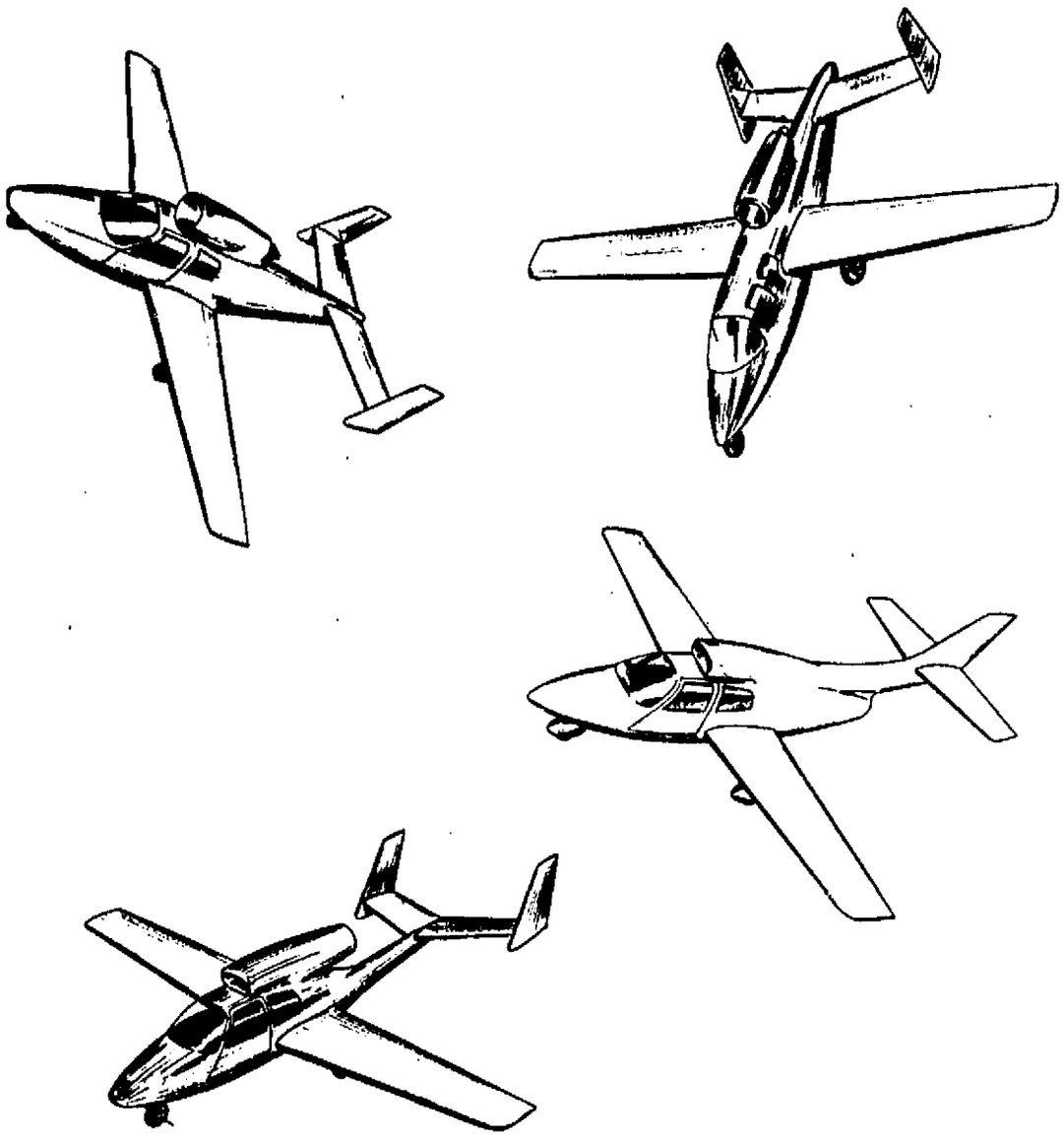


Figure 8. Design Concepts. Configurations Featuring Overhead Inlets.

Design Concepts

FINAL DESIGNS CONSIDERED

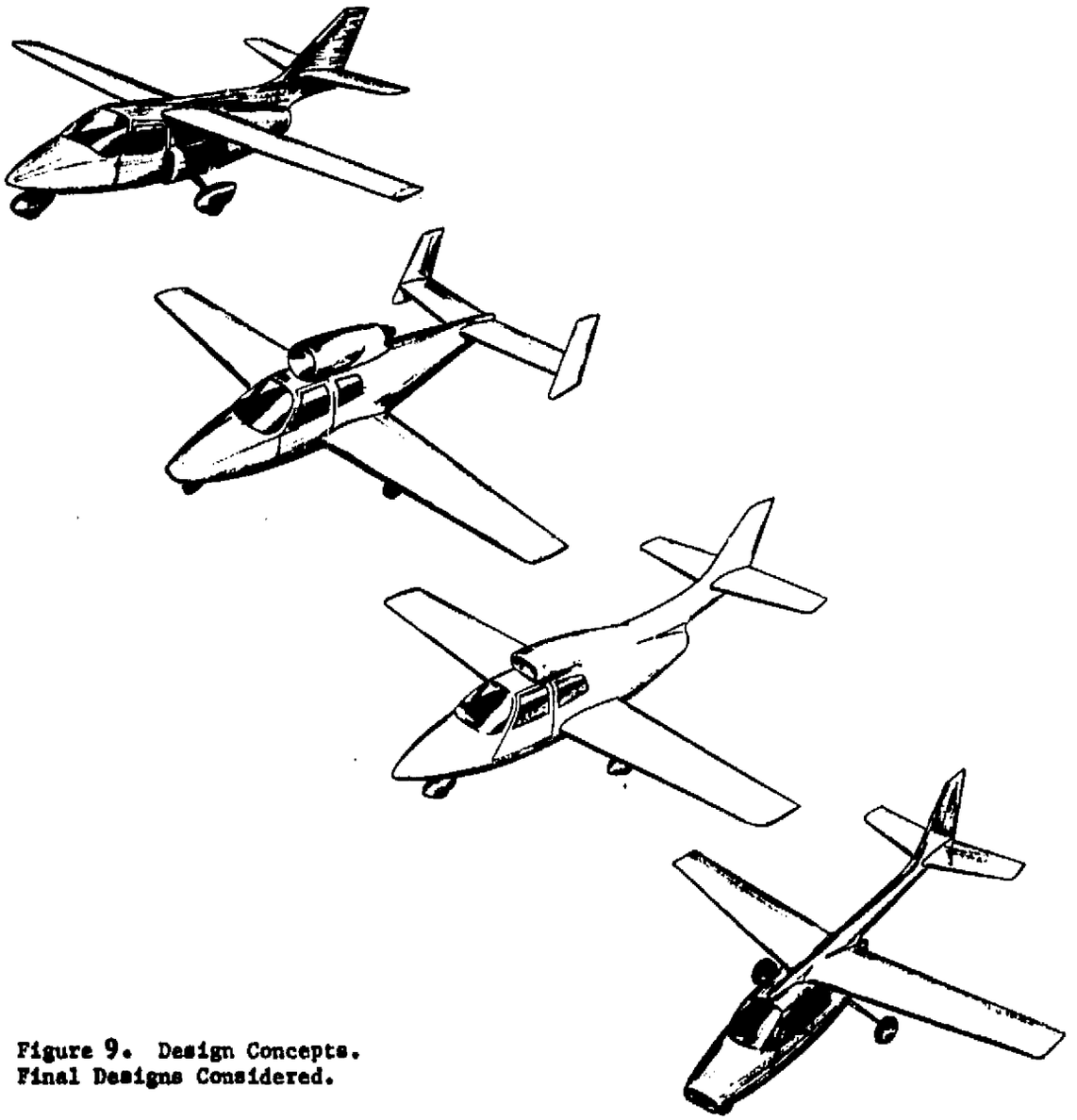


Figure 9. Design Concepts.
Final Designs Considered.

3.2.1.2 Final Design

The remaining design of the 4 finalists became the Cessna baseline, shown in Fig. 10 for the 2-place and in Fig. 11 for the 4-place. As in any design, it is the result of many compromises. Overall, the following characteristics should be noted:

1) The inlet airflow will be undisturbed in all flight regimes including stalls.

2) There is no danger to a deplaning passenger if the engine is running, nor is there any danger of the engine being damaged by its sucking up runway debris.

3) The crew visibility is excellent.

4) The design is conventional and offers low development risk and cost.

5) There is considerable commonality between the two aircraft. The nose section and forward cabin and the tailcone aft of the inlet nacelle (except for the internal engine duct) can be used for both planes.

The wing of the 4-place design would be developed from that of the 2-place by adding a root plug to increase the area and span.

The engine installation is shown in Fig.'s 12 and 13. These figures show ducts sized for the engines in Garret's 2- and 4-place planes of Ref. 1. The engines were rated at 216 lbs and 404 lbs SLST respectively.

There was much concern when this design was first considered as to whether the exhaust duct losses would be prohibitive. A short Cessna study was run that indicated that the loss in thrust was on the order of 6% relative to the Garrett installation. This loss was considered acceptable in light of the advantages of the other design features. The inlet duct losses were assumed to be similar to those of the Garrett design for which the data was supplied, and no additional penalty was assessed for the different inlet design.

The wings shown on these 3-views were only drawn to make the views complete. The actual wing geometry and size is the product of a complex design process that is outlined in the following sections. It is the result of considering a large matrix of values and determining which values optimize the economics of the airplane.

Since experience indicates that engine size has little, if any, effect on optimum wing geometry, this design process began by fixing the engine size and exploring the following matrix* of wing geometry.

*The choice of the values in this matrix is based on 1) a desire to survey a large set of variables (since the turbofan is new to general aviation, the conventional ranges of the values may no longer be adequate) and 2) the necessity of limiting the set to those values which experience has indicated are reasonable from a structural and manufacturing standpoint.

TABLE 3

WING GEOMETRY MATRIX

Taper ratio	.5, .75, 1.00
Thickness ratio (root-tip)	.15-.11,.17-.13,.19-.15
Aspect ratio	6, 9, 12

After selecting the optimum wing geometry, the wing area and engine thrust v re varied to give the minimum DOC plane. The results of these studies are found in Sections 3.2.2 through 3.2.6 and 4.2.1 through 4.2.2.

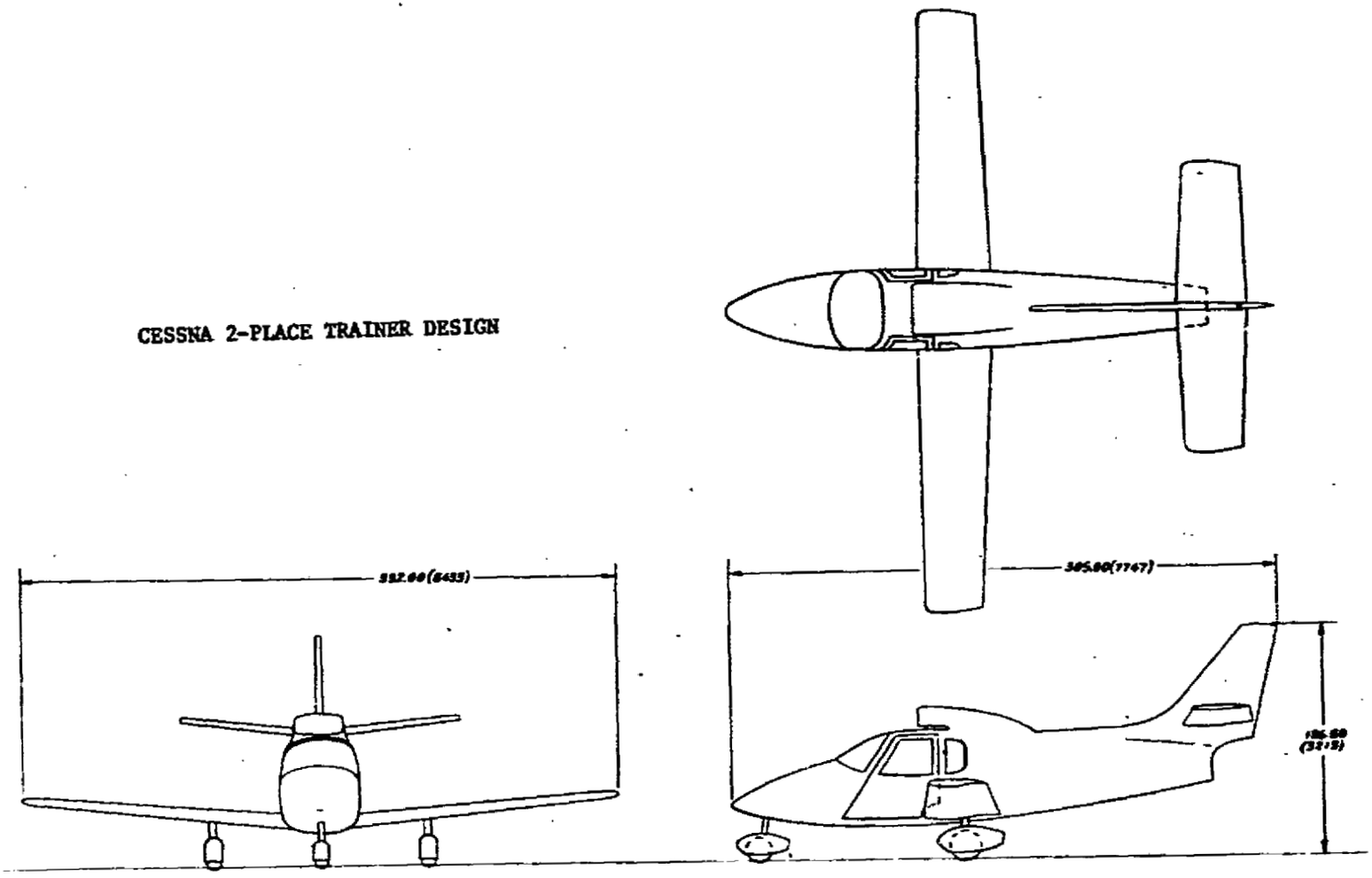


Figure 10. Baseline Design Of Cessna's 2-Place Trainer. Preliminary Configuration.

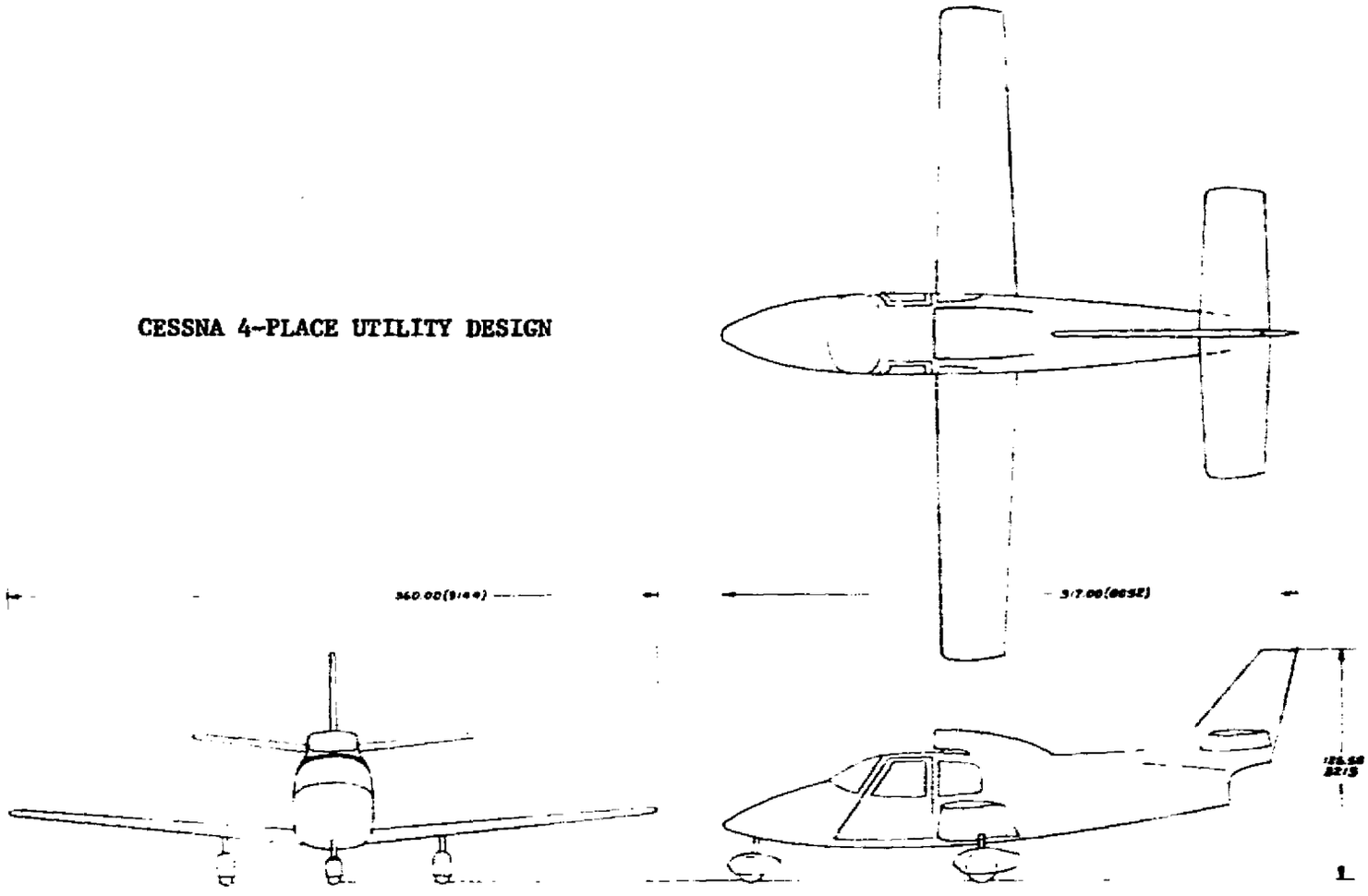


Figure 11. Baseline Design of Cessna's 4-Place LSE. Preliminary Configuration.

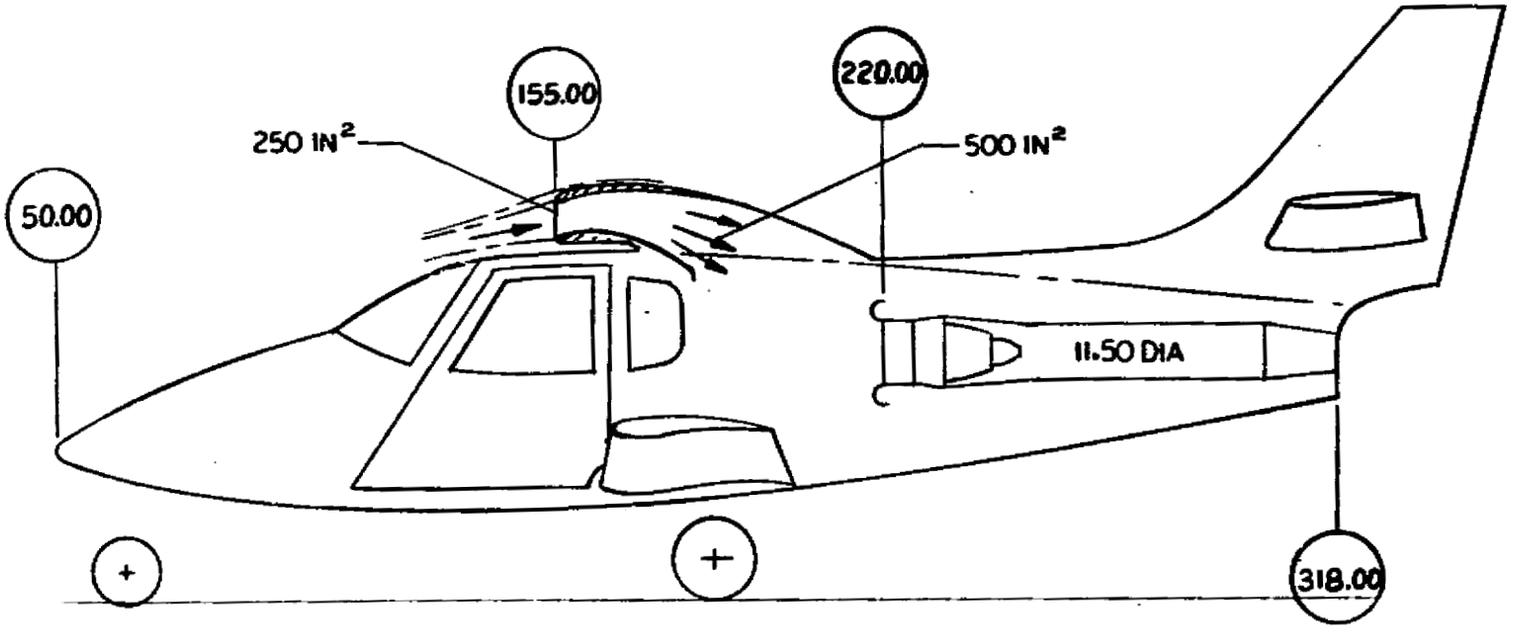


FIGURE 12 ENGINE INSTALLATION FOR CESSNA'S 2-PLACE TRAINER

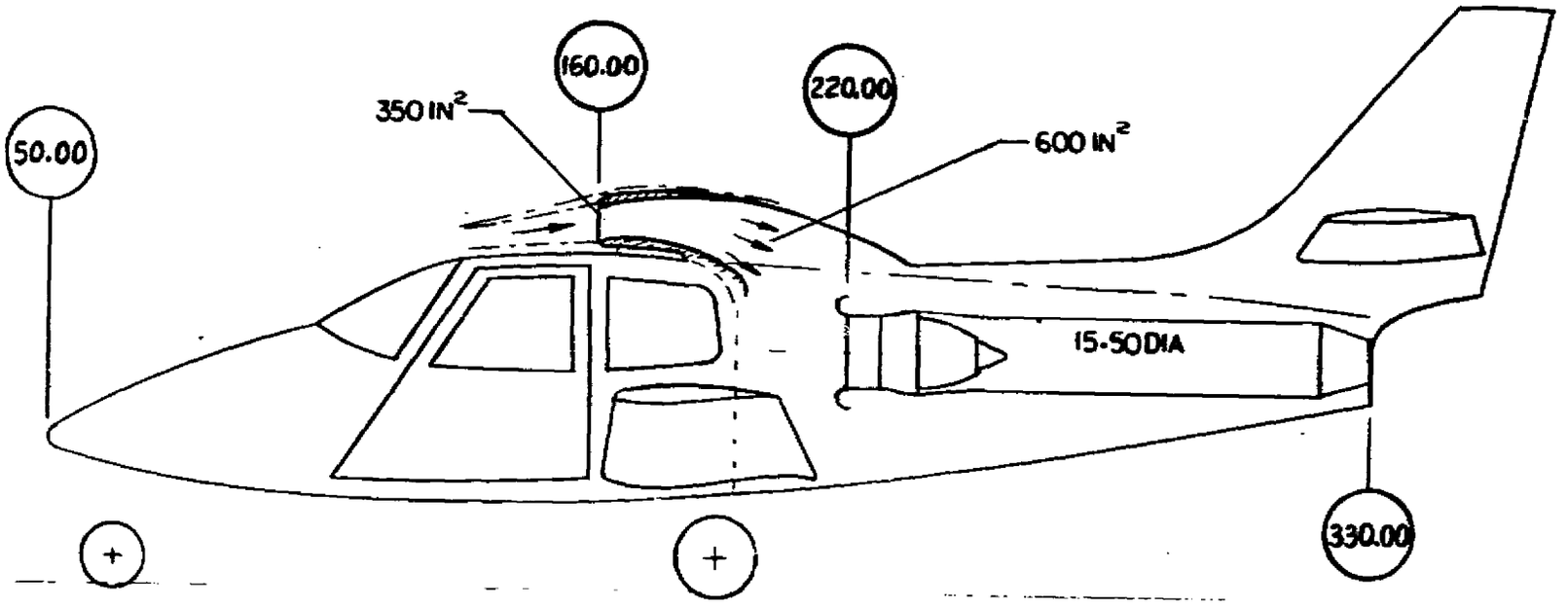


FIGURE 13 ENGINE INSTALLATION FOR CESSNA'S 4-PLACE LSE

3.2.2 Lift

3.2.2.1 Lift Methodology

The wing lift and maximum lift coefficient are effected by taper ratio and aspect ratio and by the value and distribution of the dihedral, thickness ratio, twist and airfoil sections.

Efforts to account for these effects by purely empirical means have been made. However, this has proven impractical due to the sheer number of possible variations of the design parameters and the mutual interactions of their effects.

Therefore, it is necessary to use an exact method, based on theoretical considerations, that can account for each of these effects. The approach to determining $C_{L_{MAX}}$, taken here, is the combination of a lifting line theory to determine span loading with two-dimensional wind tunnel data for the chosen airfoil sections. The lifting line theory uses Fourier analysis to determine the spanwise lift distribution for an arbitrary apportionment of chord, twist, dihedral, and airfoil on a straight wing configuration.

Maximum wing lift is determined by using input maximum lift, as a function of Reynolds number, for the airfoil sections along the wing span (for example see Fig. 14). At a particular wing Reynolds number the section maximum lift distribution across the entire span of the wing, based on the appropriate local Reynolds number, is determined. Then by a convergent iteration scheme the angle of attack at which the wing section lift distribution becomes tangent to the section maximum lift distribution is found. At this angle the spanwise loading is integrated to determine the wing $C_{L_{MAX}}$.

The result (see Fig. 20 for example) of this process can also be used to evaluate the stall characteristics. Ref. 14 suggests as a criterion for good stall characteristics, that a c_l margin of at least .15 at 70% semispan be maintained.

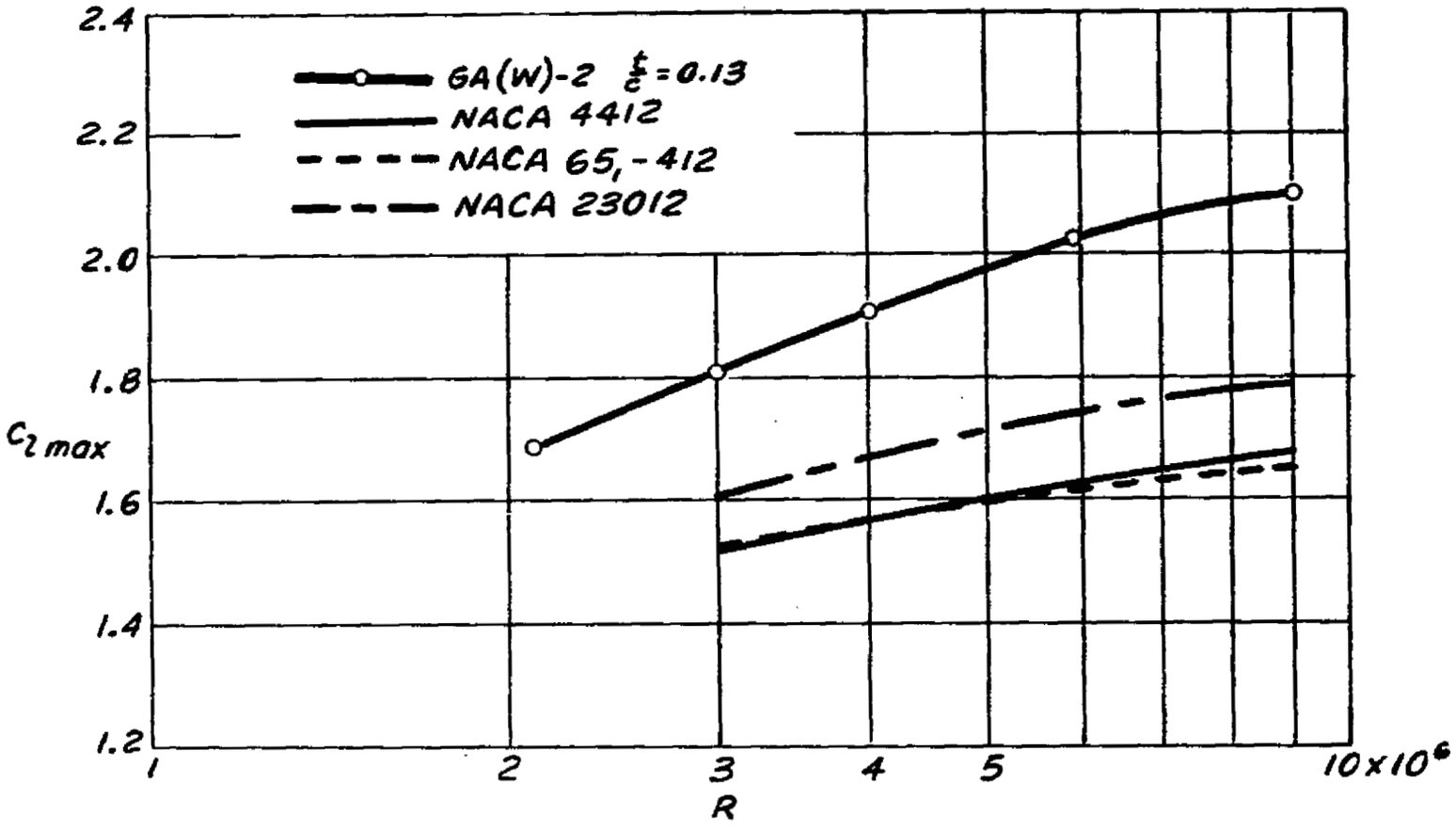


Figure 14. Variation Of Maximum Section Lift Coefficient With Reynolds Number For Various Airfoils. M = 0.15; Airfoils Smooth.

3.2.2.2 Evaluation Of Baseline

In order to evaluate the influence of wing parameters upon the maximum lift coefficient, the aspect ratio, taper ratio, and thickness ratio were systematically varied over the matrix outlined in Table 3 of section 3.2.1.2. Figure 15 shows that in general, with constant wing area, as the aspect ratio increases the maximum lift coefficient decreases. This is due to the fact that the mean chord, and therefore the Reynolds number, is decreasing with increasing aspect ratio. As shown in Fig. 14 a decrease in Reynolds number decreases the section maximum lift available.

The influence of thickness ratio on $C_{L_{MAX}}$ is illustrated in Fig. 16. The two-dimensional trends for maximum lift coefficient shown in Fig. 17 are realized in three dimensions and the $C_{L_{MAX}}$ decreases with increasing thickness ratio.

Wing taper ratio influence on $C_{L_{MAX}}$ is shown in Fig. 18. Trends for this trade are not so easily delineated as with AR and thickness. The effect of taper ratio on $C_{L_{MAX}}$ is more pronounced at low aspect ratio than at high and for the matrix studied the $C_{L_{MAX}}$ has a maximum value between taper ratios of .5 to .75.

At subsonic speeds the wing $C_{L_{MAX}}$, for high aspect ratio wings, is directly related to the maximum lift of the wing airfoil section, with planform geometry of secondary importance.

3.2.2.3 Justification

The Cessna maximum lift methodology has been justified by comparing the results of wind tunnel tests and flight test data to values predicted by the lift routines. Fig's. 19 and 20 represent the maximum lift coefficient solution for two wind tunnel models. The dashed line in these figures represents the distribution of section maximum lift along the semispan and the solid line represents the lift distribution. For these two cases the maximum error in the calculated results is 3.67%. Similar results have been produced for full scale aircraft with the maximum error usually being less than 5%.

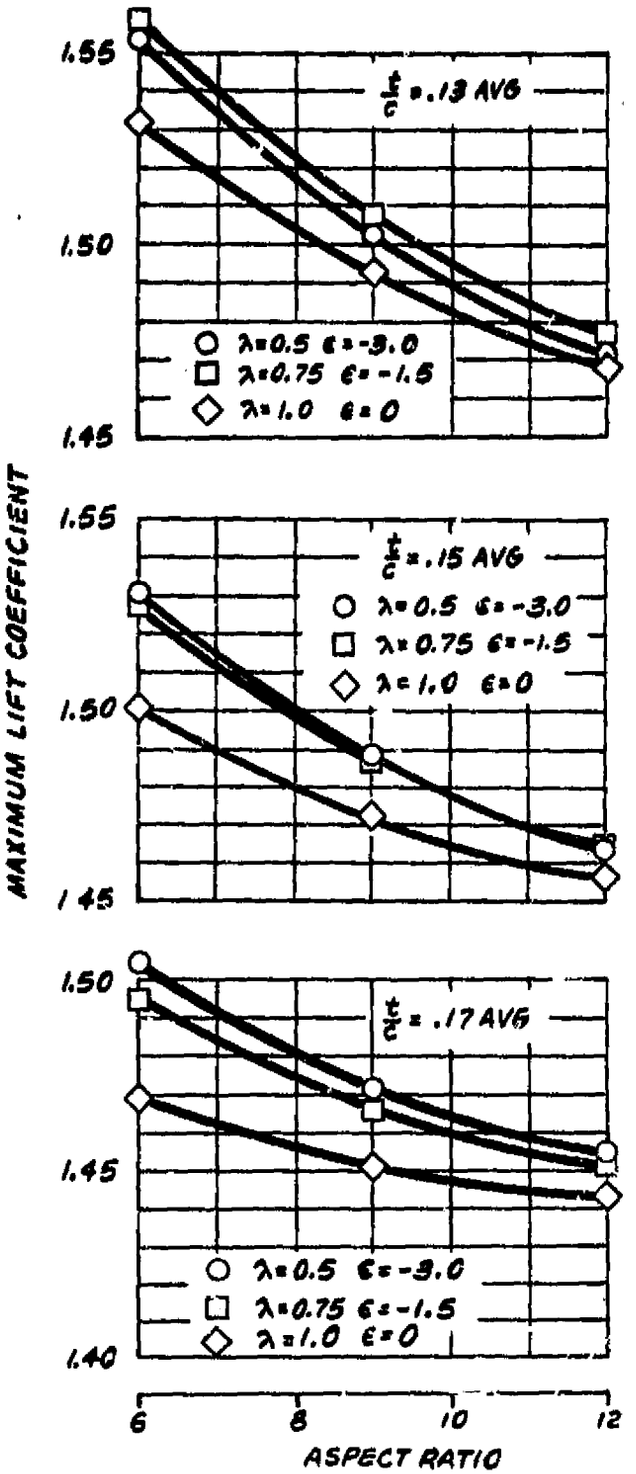


Figure 15. Effect Of Aspect Ratio On $C_{L_{MAX}}$ @ Constant Wing Area.

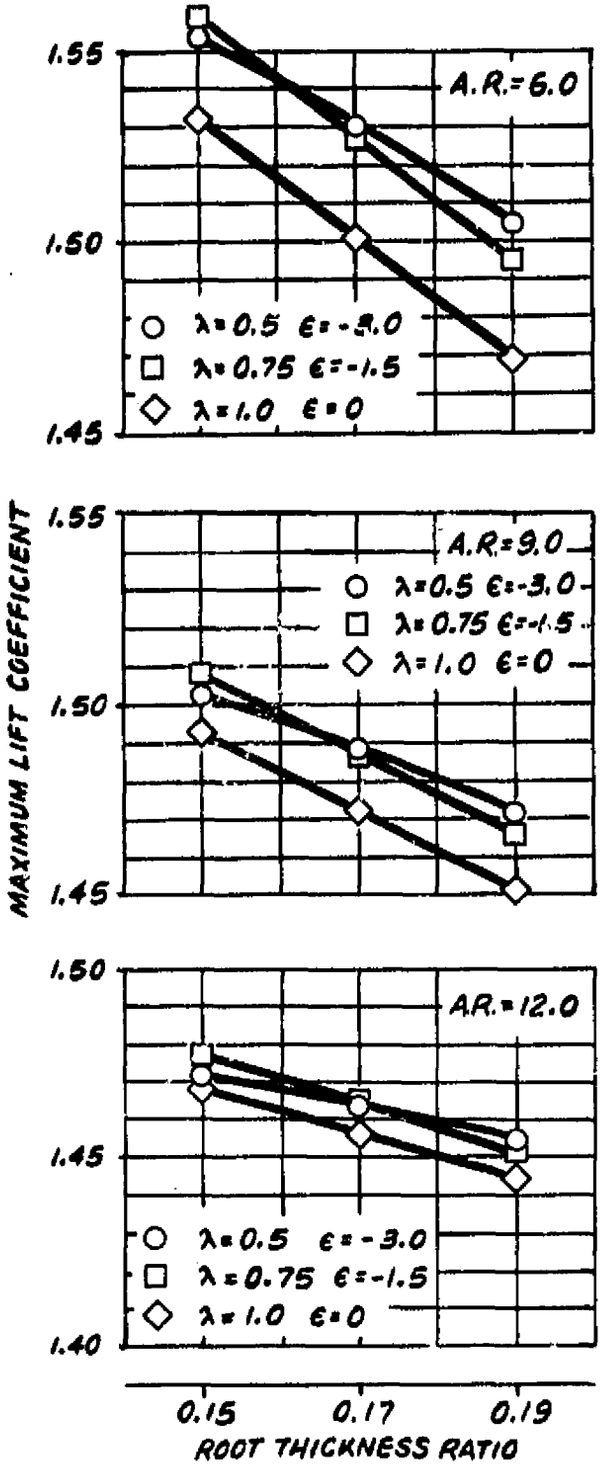


Figure 16. Effect Of Thickness Ratio On $C_{L_{MAX}}$ @ Constant Wing Area.

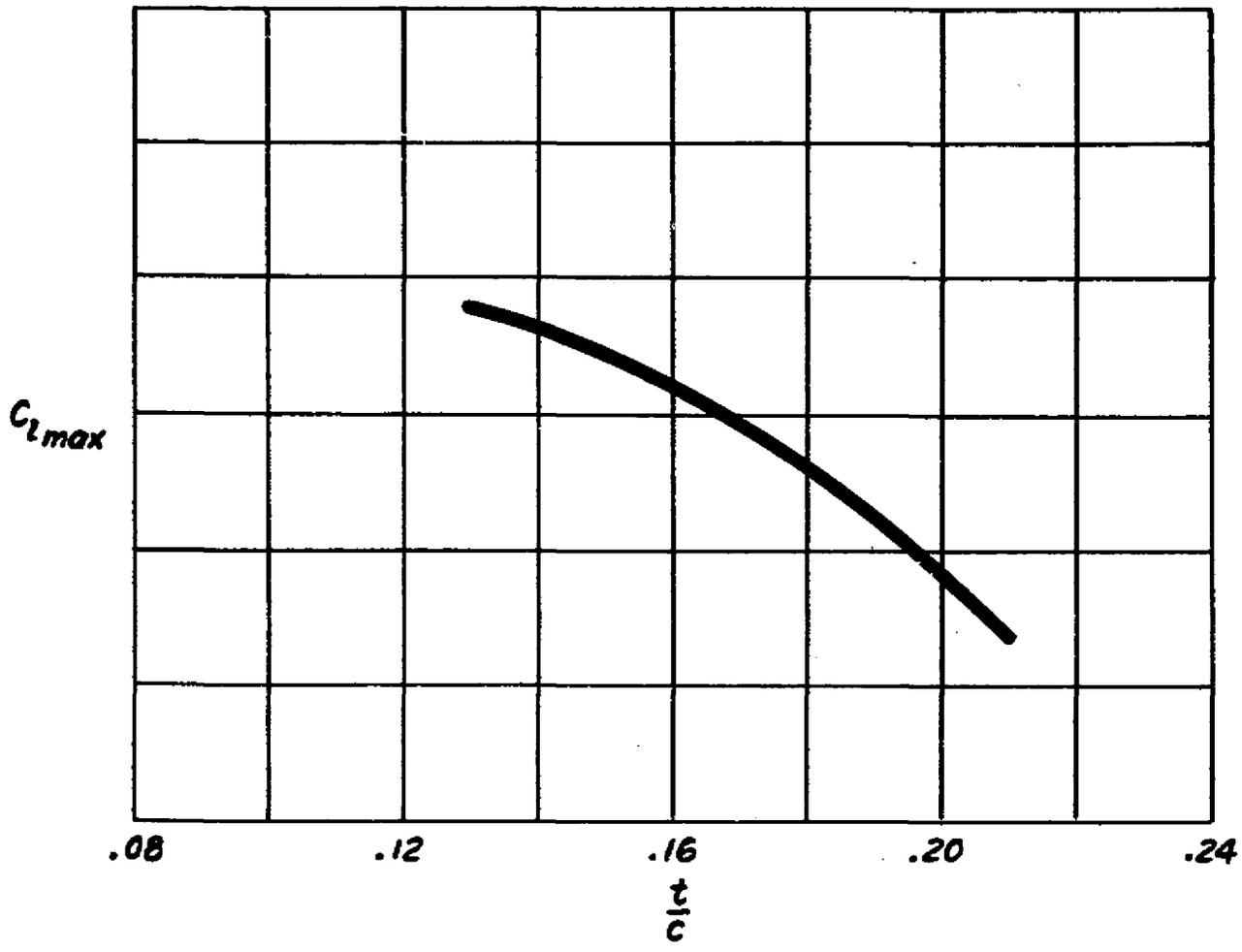


Figure 17. Effect Of Thickness Ratio On Section Maximum Lift Coefficient $c_{l_{max}}$

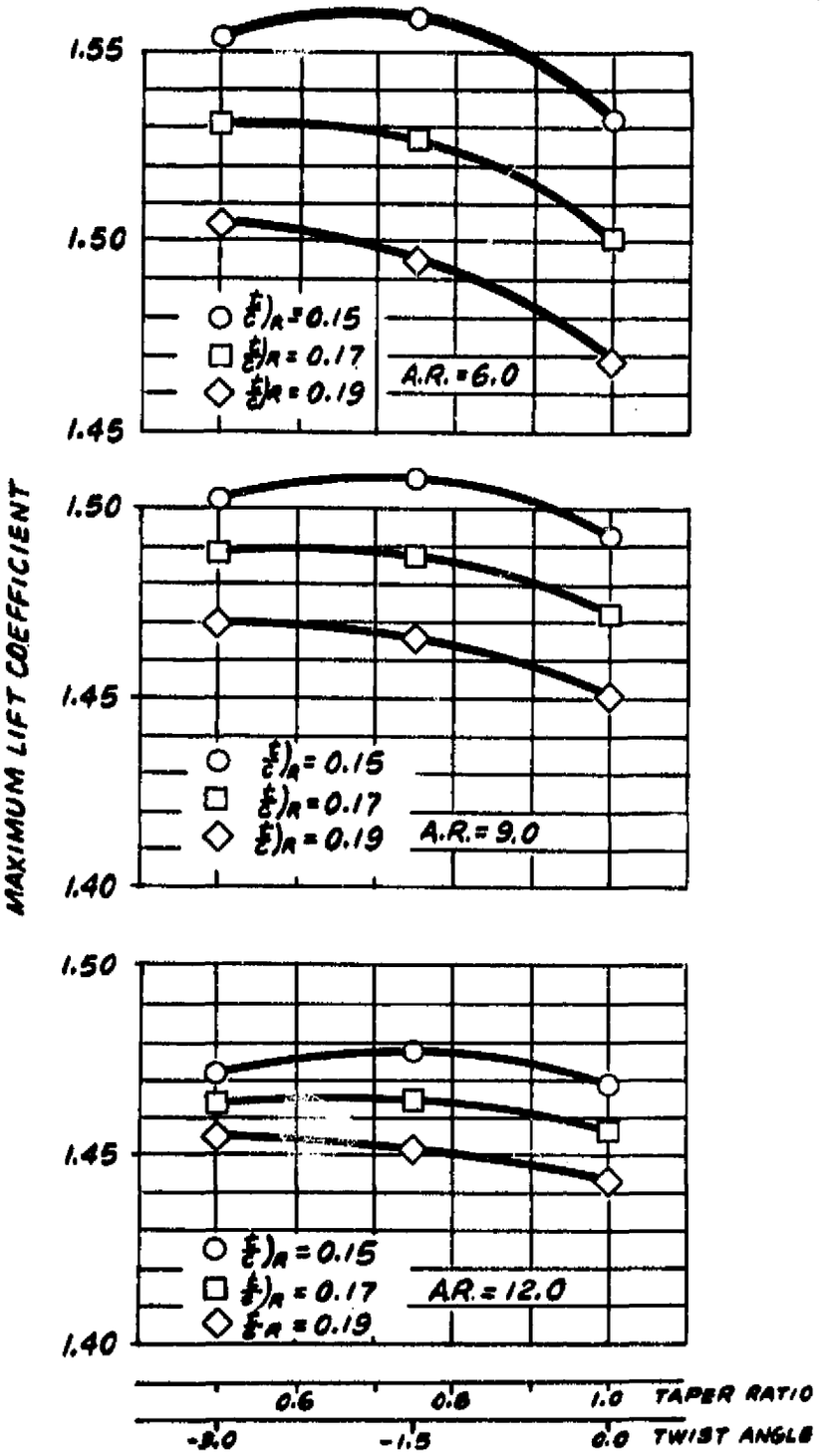


Figure 18. Effect Of Taper Ratio On $C_{l_{MAX}}$ @ Constant Wing Area.

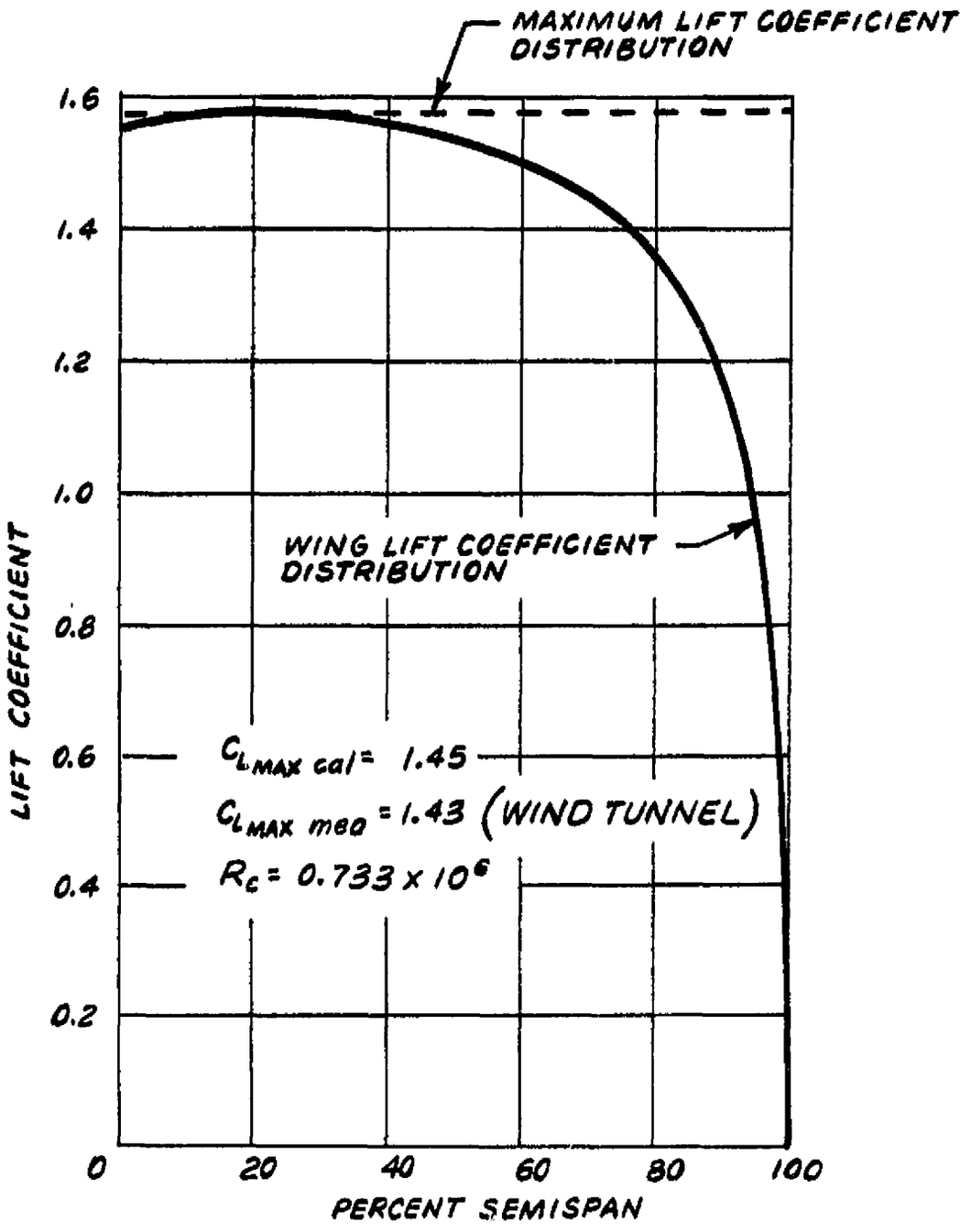


Figure 19. Comparison Of Calculated And Measured Values Of $C_{L_{MAX}}$

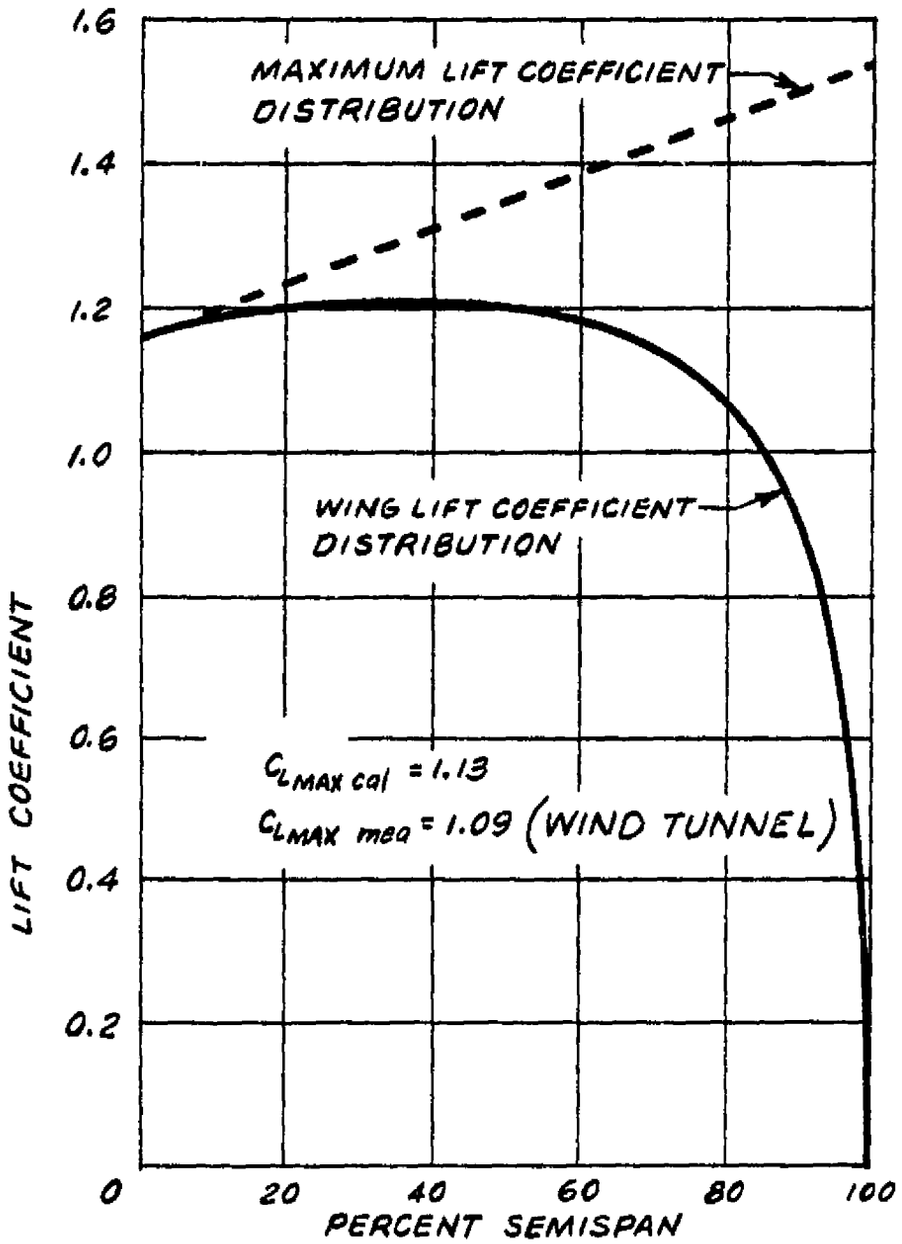


Figure 20. Comparison Of Calculated And Measured Values Of $C_{L_{MAX}}$

3.2.3 Drag

3.2.3.1 Drag Methodology

Airplane drag is assumed to be divided into two parts; equivalent parasite drag and induced drag. Compressibility drag is assumed to be negligible where cruise Mach no. is less than 0.5. The Cessna method for drag estimation incorporates DATCOM methodology (DATCOM section 4.5.3) for parasite drag and uses an empirical method for estimating the Oswald efficiency factor, "e".

The basis for the parasite drag estimation method is the skin friction method of DATCOM. Once the skin friction drag has been calculated it is multiplied by an empirical correction factor to get the total parasite drag of the airplane without landing gear. The gear drag estimate is then added to get the total parasite drag. The empirical correction factor accounts for all interference contributions of the wing-fuselage, wing-nacelle, and all miscellaneous drag items.

The empirical method for estimating the Oswald efficiency factor has been modified by Cessna to provide better agreement with general aviation aircraft. This method, which accounts for the variation of parasite drag with angle of attack as well as for the induced drag, makes "e" a function of the estimated parasite drag and the aspect ratio. Typical values of "e" are shown in Fig. 21.

3.2.3.2 Evaluation Of Baseline

The sizing program, using the input fuselage wetted area (which is not varied by the program) and the areas of wings and tail, calculates the aircraft wetted area. The equivalent parasite drag is then determined on the wetted area and the empirical correction factor discussed in section 3.2.3.1.

For conventional aircraft similar to models already in production, the empirical correction factor is known. For newer configurations (such as the baseline) greater reliance is placed on the data in Fig. 22 which shows equivalent parasite area (flat plate area) as a function of wetted area. On this graph are shown several Cessna products, a Cessna estimate for the Windecker Eagle (included because of its extreme aerodynamic cleanliness) and lines of equivalent friction coefficient ($C_{f_{equiv}}$). The baseline most nearly matches the Cessna 177B in configuration; i.e. fixed gear, cantilever wing; however there is neither prop wash nor cooling drag associated with a turbofan engine and therefore a level of $C_{f_{equiv}} = .006$ was chosen. The wetted area of the aircraft with the largest wing area of the matrix to be investigated in the sizing routine (see section 4.2.1 and 4.3.1) is then calculated and the drag is estimated for the chosen value of $C_{f_{equiv}}$. Working backward from this, an empirical correction factor of 1.052 was obtained and used as discussed in section 3.2.3.1. This factor is used for all other planes in

the sizing matrix and results in higher levels of $C_{f_{equiv}}$ for planes with smaller wing areas.

The Oswald efficiency factor is determined by the sizing program from the aspect ratio and parasite drag.

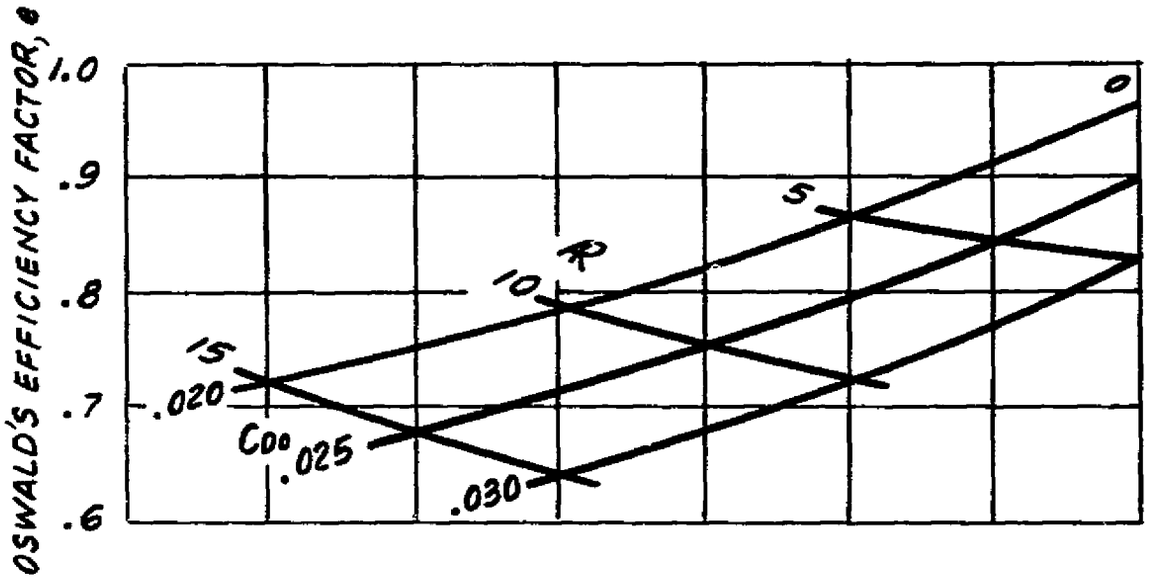


Figure 21. Effect of AR and Parasite Drag on Oswald's Efficiency Factor.

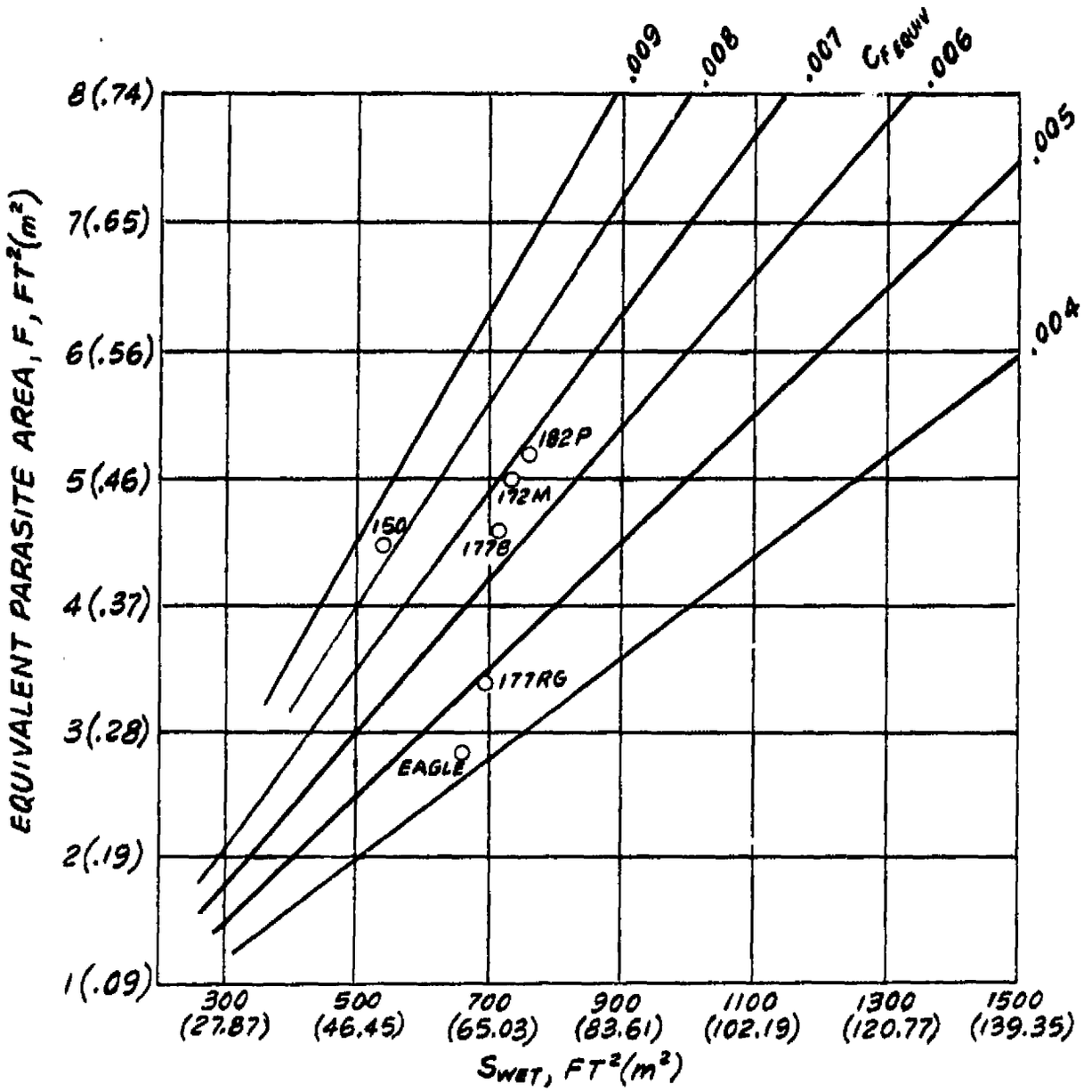


Figure 22. Equivalent Parasite Area

3.2.4 Weights

3.2.4.1 Weight Estimating Methodology

Cessna's methodology for weight estimation is based on empirical relationships for a 13 component breakdown. This method provides a realistic evaluation of the various components using the riveted aluminum framework construction utilized in the fabrication of present day aircraft. For bonded aluminum wing construction, data points were obtained from Cessna's current bonded assemblies and from several Cessna design proposals in which the bonding technique was considered for assembly.

Aircraft used to determine the equations for weight estimating range from the 1600 pound Model 150 to the 5500 pound Model 310.

3.2.4.1 (a) Breakdown Of Components

The component breakdown used in estimating the dry empty weight is as follows:

1) Wings - Includes fuselage carrythru for spars, attachment hardware, and fairing strips. Includes struts and strut fairings on braced wing.

2) Fuselage - Includes fuselage shell structure, floorboards, seat rails, doors, windows, support brackets and wing, tail, and gear attachment hardware.

3) Powerplant Installation - Includes everything supported by the engine mount. This value is usually provided by the engine and accessory manufacturers.

4) Nacelle - Three types of nacelles were considered for the determination of the nacelle weight. The wide variation in nacelle configurations will limit the accuracy of the nacelle weight predicition.

I For single engine aircraft the nacelle weight consists of the cowling, cowl mounting hardware and engine mount.

II For multi-engine aircraft the nacelle weight consists of the cowling, firewall, nacelle fairing aft of the firewall, and the engine mount.

III For small jet engine aircraft the nacelle weight consists of the engine fairing (or inlet scoop) and the engine mount.

5) Vertical Tail - Includes vertical tail structure, attachment fittings and hardware, trim tab, and rudder balance.

6) Horizontal Tail - Includes horizontal tail structure, attachment fittings and hardware, trim devices, and elevator balance.

7) Main Gear Assemblies - Includes shock absorber, strut fairings (if applicable), brakes, wheels, and fittings.

8) Nose Gear Assembly (or tail gear assembly) - Includes shock absorber, fairing (if applicable), shimmy dampening, steering linkage, wheel, and fittings.

9) Retraction System - Includes actuators, plumbing, emergency hand pump, selectors, valves and fluid.

10) Control System - Includes flight and engine controls.

11) Equipment - Includes electrical equipment (battery, box, regulator, wiring, etc.) and standard minimum flight instruments.

12) Furnishings - Includes seats, upholstery, sound proofing material, restraint system, and heat and ventilation system.

13) Miscellaneous Items - All items not covered in the major breakdown above and special to the chosen design configuration.

3.2.4.1 (b) Determining Basic Empty Weight

The dry empty weight (DEW) is the sum of the components listed in the previous section. The basic empty weight (BEW) is the sum of the dry empty weight, engine oil, unusable fuel, and optional equipment.

The optional equipment is an itemized list of specific equipment, usually taken to be that equipment typically installed in aircraft similar to the design configuration. It is not possible to adequately represent these items with any trend equation. Therefore, for the initial baseline aircraft, the Cessna Cardinal II, with Nav Pac, was used for an optional equipment breakdown that could be considered typical of the 4-place baseline design. For simplicity's sake this was also used during the initial work on the 2-place baseline.

3.2.4.1 (c) Deriving Weight Trend Equations

The weight estimating methods are used to determine the basic empty weight for a range of gross weights and wing areas, bracketing the estimated values. From this can be found a relationship (trend equation) between gross weight, wing area, and empty weight. The equation is of the form:

$$BEW = k_1 + k_2 \ (W)$$

$$\text{Where} \quad k_1 = a_1 + a_2 \ (S_W)$$

$$k_2 = a_3 + a_4 \ (S_W)$$

Note that the equations are linear. Experience has shown this to be an adequate representation over a limited gross weight range.

3.2.4.1 (d) Usage Of The Weight Trend Equation

For the initial baseline aircraft 27 weight trend equations were derived for the wing geometry matrix of section 3.2.1.2. These equations were then used by the sizing program to determine the fuel capacity and basic empty weight as gross weight and wing area were varied to match the design requirements. A detailed analysis of one of these 27 cases is shown on the following pages to illustrate the procedure described above.

3.2.4.2 Evaluation Of Baseline

The following weight estimation of the major components of the initial baseline aircraft will illustrate the methodology described in the previous section 3.2.4.1. The initial baseline input used for the weight estimate is listed below:

S_W = 85.0 $ft.^2$ (wing area)
AR = 9.0 (aspect ratio)
λ=.75 (taper ratio)
$t/c)_r$ = .17 (root wing thickness)
W = 1400 lbs. (gross weight)
S_V = 16.2 $ft.^2$ (vert. tail area)
S_H = 26.6 $ft.^2$ (horiz. tail area)
n' = 5.7 (design load factor)
SLST = 300 lbs. (sea level static thrust)

3.2.4.2 (a) Component Weight Estimate

1. Wing (complete with carrythru)
   $W_W = 69\ (B \times 10^{-6})^{.69}$
   Where $B = \dfrac{W\ n'\ S_W\ (1.9 * AR\ \ -4)}{1 + 11\ t/c)_r}$

Note: Similar to K.L. Sanders graph in Ref. 5.
Used for cantilever wings only.

$$B = \frac{1400\ (5.7)\ 85.0\ (1.9\ (9)\ \ -4)}{1 + 11\ \ (.17)} = 3.09607 \times 10^6$$

$W_W = 69(3.09607)^{.69}$ = 150.5 lbs. (68.27 Kilograms)

2. Fuselage
   W_{fus} = .11 W = .11(1400) = 154.0 lbs. (69.85 Kg.)
3. Powerplant Installation
   W_{pp} = .28713 SLST = .28713 (300) = 86.1 lbs. (39.05 Kg.)
   Reference Garrett Dwg. SKP-17547
4. Nacelle (external inlet scoop and engine mount)
   W_n = .046 SLST = .046 (300) = 13.8 lbs. (6.26 Kg.)
5. Vertical Tail
   W_V = 1.28 S_V = 1.28 (16.2) = 20.7 lbs. (9.39 Kg.)
6. Horizontal Tail
   $W_H = 1.2\left[\dfrac{W}{3000}\right]^{.25} S_H = 1.2\left[\dfrac{1400}{3000}\right]^{.25}(26.6)$ = 26.4 lbs. (11.97 Kg.)
7. Main Gear Assembly
   W_{mg} = .019W+38 = .019 (1400)+38 = 64.6 lbs. (29.30 Kg.)
8. Nose Gear Assembly
   W_{ng} = .006W+19 = .006 (1400)+19 = 27.4 lbs. (12.43 Kg.)
9. Retraction System (not applicable)
10. Control System (for light single engine aircraft)
    W_c = 40 lbs. (18.14 Kg.)

11. Equipment
$W_e = 35+.01W = 35 + 14 = 49.0$ lbs. (22.23 Kg.)

12. Furnishings
$W_f = 40$ (No. of occupants) $= 40(2) = 80$ lbs. (36.29 Kg.)

13. Miscellaneous Items
Determined weight of materials for approximate physical shape.

a) Engine inlet duct (Internal)

W_{id} = 12 lbs. (5.44 Kg.) (formed alum. sheet metal duct approx. 13" dia. and approx. 75" long and rivets)

b) Engine tailpipe (Internal)

W_{tp} = 34.5 lbs. (15.65 Kg.) (stainless steel duct approx. 15" dia. and 80" long)

Dry Empty Weight = Σ Component weight = 759.0 lbs. (344.28 Kg.)

3.2.4.2 (b) Basic Empty Weight Estimate

	Pounds	Kilograms
Dry Empty Weight	759.0	344.28
Oil (1 quart)	1.9	.86
Unusable Fuel (1 gallon)	6.7	3.04
Typical Optional Equipment (listed below)	89.2	40.46
Basic Empty Weight	856.8	388.64

Typical Optional Equipment Breakdown

Wheel and brake fairings		18.0	
Gyros, Hor. and Dir.		6.0	
Light-map		.2	
Tow bar		1.6	
Vacuum system		4.2	
Primary group		5.9	
Overall paint		7.0	
True airspeed indicator (each)		.1	
Heated pitot		.9	
Dual controls		4.1	
Light-courtesy		1.0	
Static Air Att. source		.5	
ELT		1.8	
300 Nav Pak	Nav/Com	14.7	
2nd	Nav/Com	10.2	
	ADF	8.4	
	Transponder	4.6	
Total		89.2	(40.46 Kg.)

3.2.4.2 (c) Weight Trend Equation

The weight range selected for the weight trend equation was 1200 to 1600 lbs. The same weight estimating procedure as shown in the previous section was used to determine the following basic empty weights.

BEW = 811.6 lbs. for 1200 lb. aircraft
BEW = 901.2 lbs. for 1600 lb. aircraft

$$k_1 = 811.6 - \frac{901.2 - 811.6}{1600 - 1200} 1200 = 542.8$$

$$k_2 \quad \frac{901.2 - 811.6}{1600 - 1200} = .224$$

$\therefore$ BEW = $k_1 + k_2$ W = 542.8 + .224 W

This analysis was repeated for a wing area of 100 ft^2 giving:

$$BEW = k_1 + k_2 W = 549.3 + .233 W$$

From this we can solve for the "a" coefficients

$$k_1 = a_1 + a_2 S_W = 505.97 + .4333 S_W$$

$$k_2 = a_3 + a_4 S_W = .173 + .0006 S_W$$

The same procedure was used to determine the weight trend equations for the wing geometry matrix in Table 3, section 3.2.1.2.

3.2.4.2 (d) Weight Distribution

This section is included to illustrate how the forward and aft loading points are selected to describe the most extreme conditions possible for the flying aircraft.

The first point to obtain for the weight distribution envelope will be the lightest possible aircraft with minimum fuel and a pilot. This is the minimum flying weight and is defined by FAR 23.25(b). The minimum fuel for this condition is the fuel necessary for one half hour of operation at rated maximum continuous power (FAR 23.25 (b) (4)).

The location of the components estimated in section 3.2.4.2. (a) and 3.2.4.2 (b) are determined from the three view drawing and the minimum flying weight c.g. is compiled as shown in Table 4. Each item of the optional equipment (section 3.2.4.2. (b)) must be visualized on the three view and compiled to find the c.g. of the total. The fuel load c.g. is located according to where it would be structurally feasible to locate a wet cell in the wing structure.

By starting with the minimum flying weight and adding the most forward items, the forward loading points are determined until the gross weight is reached as shown on the second page of Table 4. This same procedure is also used for the aft loading points. These points are then plotted on Fig. 23 and must fall within reasonable aerodynamic limits.

If the c.g. range is unreasonable, the wing is usually relocated to shift the envelope. Since the tail arms also change with wing movement, tail sizing must also be redone. The weight distribution program is repeated until a reasonable c.g. range is obtained. The flight envelope is then drawn to cover the loading points as shown by the broken line [illegible].

TABLE 4
WEIGHT DISTRIBUTION

GROSS WT = 1400 LB S_W = 85 FT² AR = 9.0 t_{cr} = .17 λ = .75 MGC = 37.129" LE of MGC = F.S. 163.00 Δx = 10" for tail

ITEM	WT	X	X-MOMENT	Σ WT	Σ X-MOMENT	C.G.	%MGC
WING (INCL CARRY-THRU)	150.5	181.56	27 325				
FUSELAGE	154.0	161.00	24 794				
POWERPLANT INSTL	86.1	232.00	19 975				
NACELLE	13.8	200.00	2 760				
VERTICAL TAIL (S_V=16.2 ft²)	20.7	325.00	6 728				
HORIZ. TAIL (S_H=26.6 ft²)	26.4	319.50	8 435				
MAIN GEAR ASSEMBLY	64.6	184.00	11 886				
NOSE GEAR ASSEMBLY	27.4	68.00	1 863				
RETRACTION SYSTEM	N.A.						
CONTROL SYSTEM	40.0	175.00	7 000				
EQUIPMENT (ELECT & STO INST)	49.0	109.00	5 341				
FURNISHINGS	80.0	140.00	11 200				
ENGINE INLET DUCT	12.0	192.00	2 304				
ENGINE TAILPIPE	34.5	278.00	9 591	759.0	139 202	183.40	54.95
DRY EMPTY WEIGHT	759.0						
OIL (1 QT.)	1.9	228.60	434				
UNUSABLE FUEL (1 GAL)	6.7	174.10	1 166				
MINIMUM FUEL	70.0	174.10	12 187				
PILOT	170.0	140.00	23 800	1007.6	176 789	175.46	33.55
MINIMUM FLYING WT	1007.6						

TABLE 4 (CONT)
WEIGHT DISTRIBUTION

	WT	X	X-MOMENT	Σ WT	Σ X-MOMENT	C.G.	%MGC
FORWARD LOADING							
MINIMUM FLYING WT	1007.6		176 789	1007.6	176 789	175.46	33.55
FWD OPTIONAL EQUPT	89.2	165.50	12 176	1096.8	188 965	172.29	25.01
COPILOT	170.0	140.00	23 600	1266.8	212 565	167.80	12.92
BAGGAGE	60.0	172.00	10 320	1326.8	222 885	167.99	13.43
FUEL TO GROSS	73.2	174.10	12 744	1400.0	235 629	168.31	14.29
AFT LOADING							
MINIMUM FLYING WT	1007.6		176 789	1007.6	176 789	175.46	33.55
FUEL TO FULL ($35\frac{2}{3}$ GAL)	239.0	174.10	41 610	1246.6	218 399	175.20	32.85
BAGGAGE	60.0	172.00	10 320	1306.6	228 719	175.05	32.45
COPILOT TO GROSS	93.4	140.00	13 076	1400.0	241 795	172.71	26.15

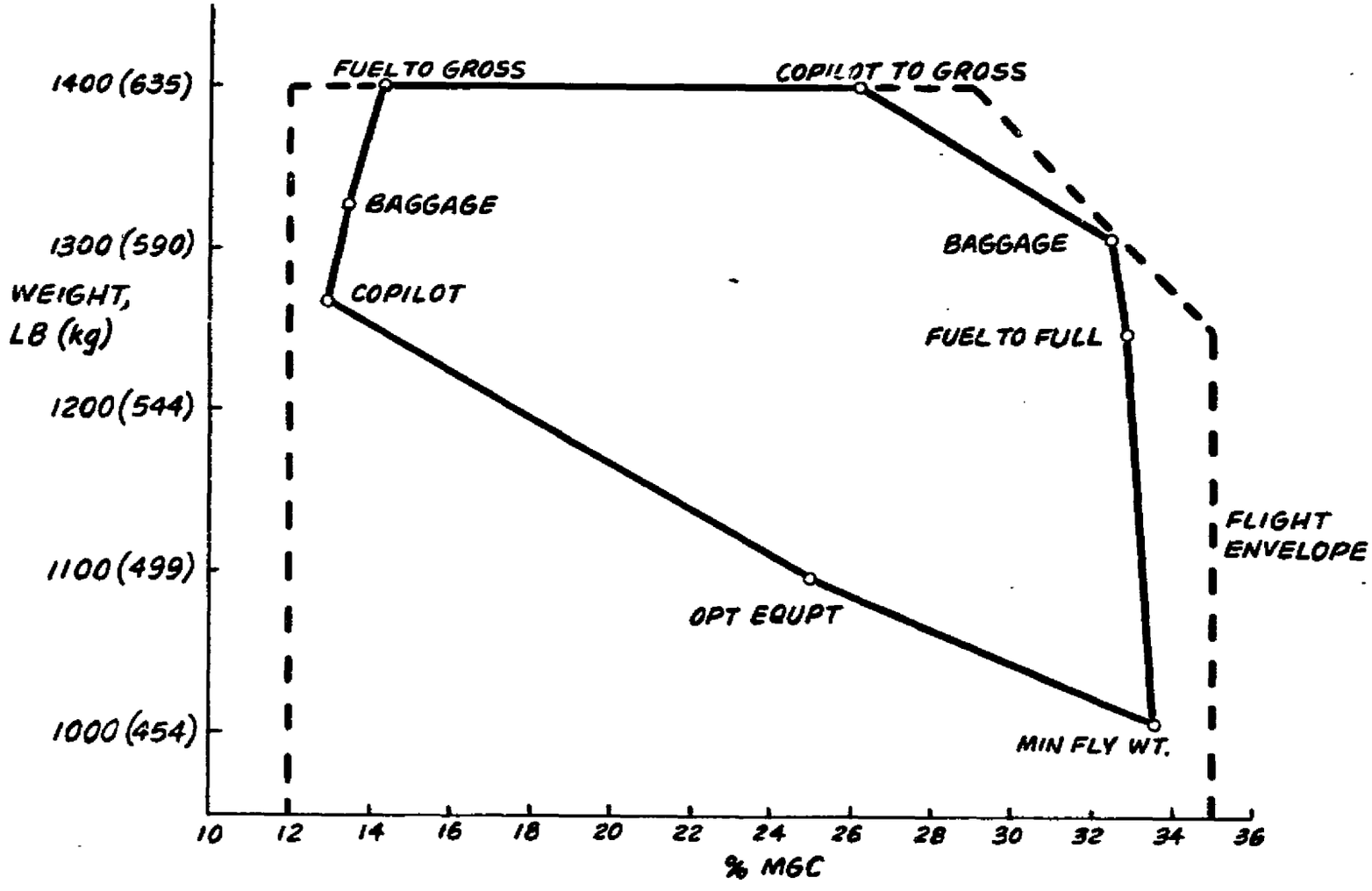


Figure 23. CG Envelope of Preliminary 2-Place Trainer Configuration.

3.2.5 Tail Size

3.2.5.1 Tail Size Methodology

Traditionally advance design methods have sized the empennage based on trend equations which in turn are based on aircraft in the same size, speed and performance category as the plane being designed. The usual correlating factors are:

For the horizontal tail $\dfrac{w_f^2 \; l_f}{S_W \; \bar{c}_W}$

For the vertical tail $\dfrac{h_f^2 \; l_f}{S_W \; b_W}$

Cessna has developed the following trend equations based on general aviation aircraft.

For the vertical tail the correlation factor is as above. The data used is shown in Fig. 24 along with the resulting curve fit. The equation is:

$$\bar{V}_V = .0025 + .435 \frac{h_f^2 \; l_f}{S_W \; b_W} \text{ for single engine aircraft}$$

The vertical tail area does not include the dorsal or ventral fin areas. The vertical tail is assumed to end at the horizontal for low tail designs. For mid and T-tail designs, the root chord of the vertical is usually taken to be a line, parallel to the fuselage reference plane, intersecting the tail where the trailing edge of the vertical meets the top of the fuselage.

The horizontal is sized against the factor:

$$\frac{w_f^2 \; \Delta x \; l_f}{S_W \; \bar{c}_W^2}$$

The trend with this factor is shown in Fig. 25 for single engine aircraft with conventional elevator-stabilizer designs. The trend equation was derived to pass through the top of the data in order to be conservative.

Incorporation of the cg range into the tail size equation is an important safeguard against optimizing the wing with too high an aspect ratio. High aspect ratio wings have small MAC's. The permissable cg range for such wings becomes very small. (Or the tail becomes very large.) Such designs only become attractive when combined with artificial stabilization systems that allow the cg range to go further back on the wing than is allowable with stable designs. Since such systems are (at least at present) impractical for general aviation, the wing chord must be kept fairly large in order to have reasonable cg ranges or tail sizes. The trend equation is:

$$\bar{V}_H = .455 + 2.325 \frac{w_f^2 \; \Delta x \; l_f}{S_W \; \bar{c}_W^2}$$ for single engine aircraft with conventional elevator-stabilizers

One further refinement is a correlation of aft cg against:

$$\bar{V}_H \quad \text{and} \quad \frac{w_f^2 l_f}{S_W \bar{c}_W}$$

which is shown in Fig. 26. The resulting equation is:

$$x_{\text{aft cg limit (STAB-ELEV DESIGNS)}} = \frac{.1938 \bar{V}_H}{\frac{w_f^2 l_f}{S_W \bar{c}_W}} + \frac{.16 w_f^2 l_f}{S_W \bar{c}_W} \quad \text{for} \quad \frac{\bar{V}_H}{\left(\frac{w_f^2 l_f}{S_W \bar{c}_W}\right)^2} \leq 4.8515$$

$$= \frac{.049 \bar{V}_H}{\frac{w_f^2 l_f}{S_W \bar{c}_W}} + .8625 \frac{w_f^2 l_f}{S_W \bar{c}_W} \quad \text{for} \quad \frac{\bar{V}_H}{\left(\frac{w_f^2 l_f}{S_W \bar{c}_W}\right)^2} > 4.8515$$

After the tail is sized against the cg range, the aft cg limit is calculated by this equation. If the calculated aft cg does not match this number, the wing is moved, or the cg range is increased so that the actual aft cg lies within the limit calculated.

3.2.5.2 Evaluation of Baseline

These trend equations are incorporated directly into the computer programs that size Cessna's aircraft. The tail arms and c.g. range are not varied (i.e. $l_H/\bar{c}_W, l_V/b_W$ and $\Delta x/\bar{c}_W$ do vary) as wing size is changed.

The tail areas thus found are used to accurately determine the wetted area and the drag variation for the different wing areas considered in the sizing matrix. These equations are also used in the determination of the weight trend equations shown in section 3.2.4.1.

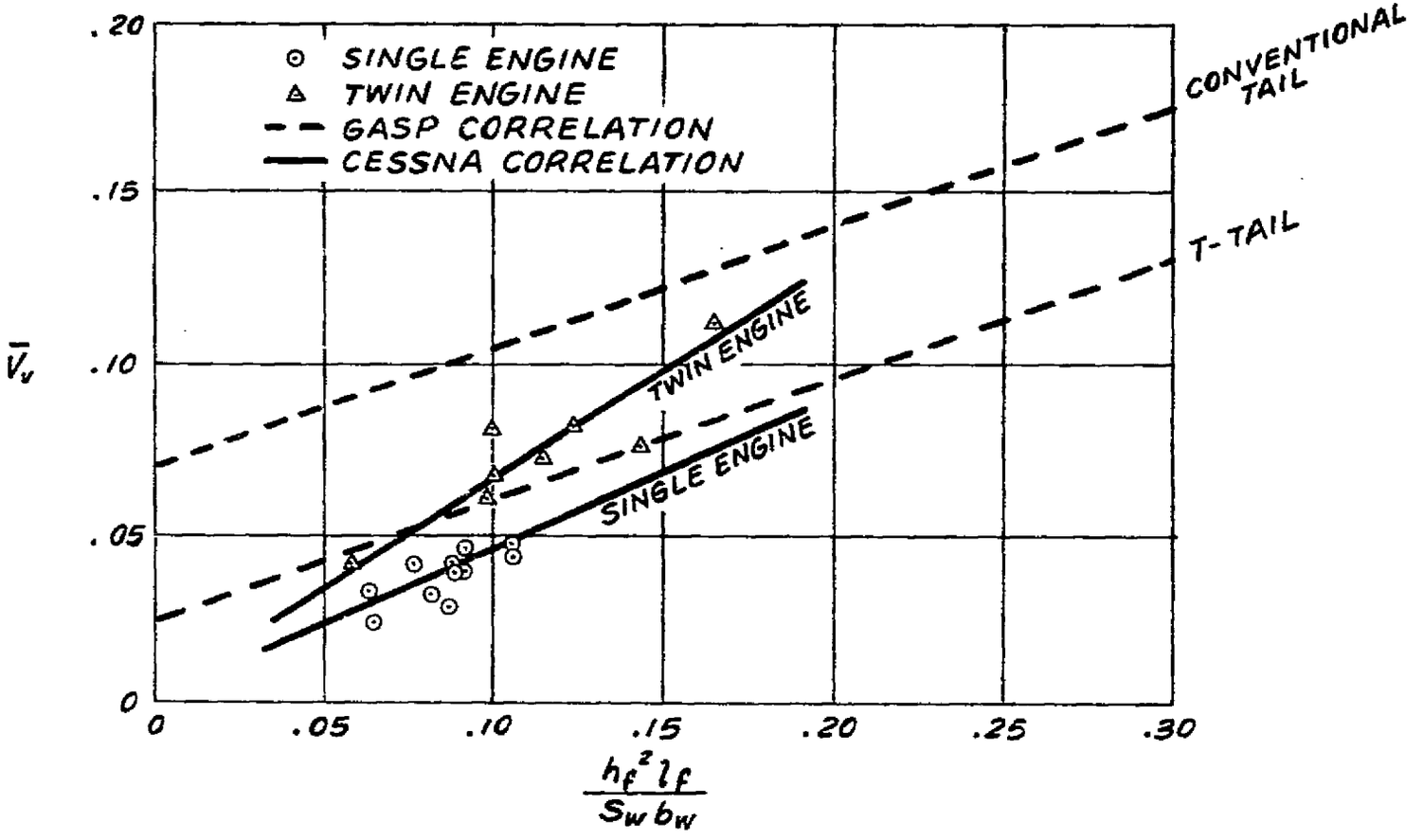


Figure 24. Correlation of Vertical Tail Volume Coefficient With Fuselage-Wing Geometry Parameters.

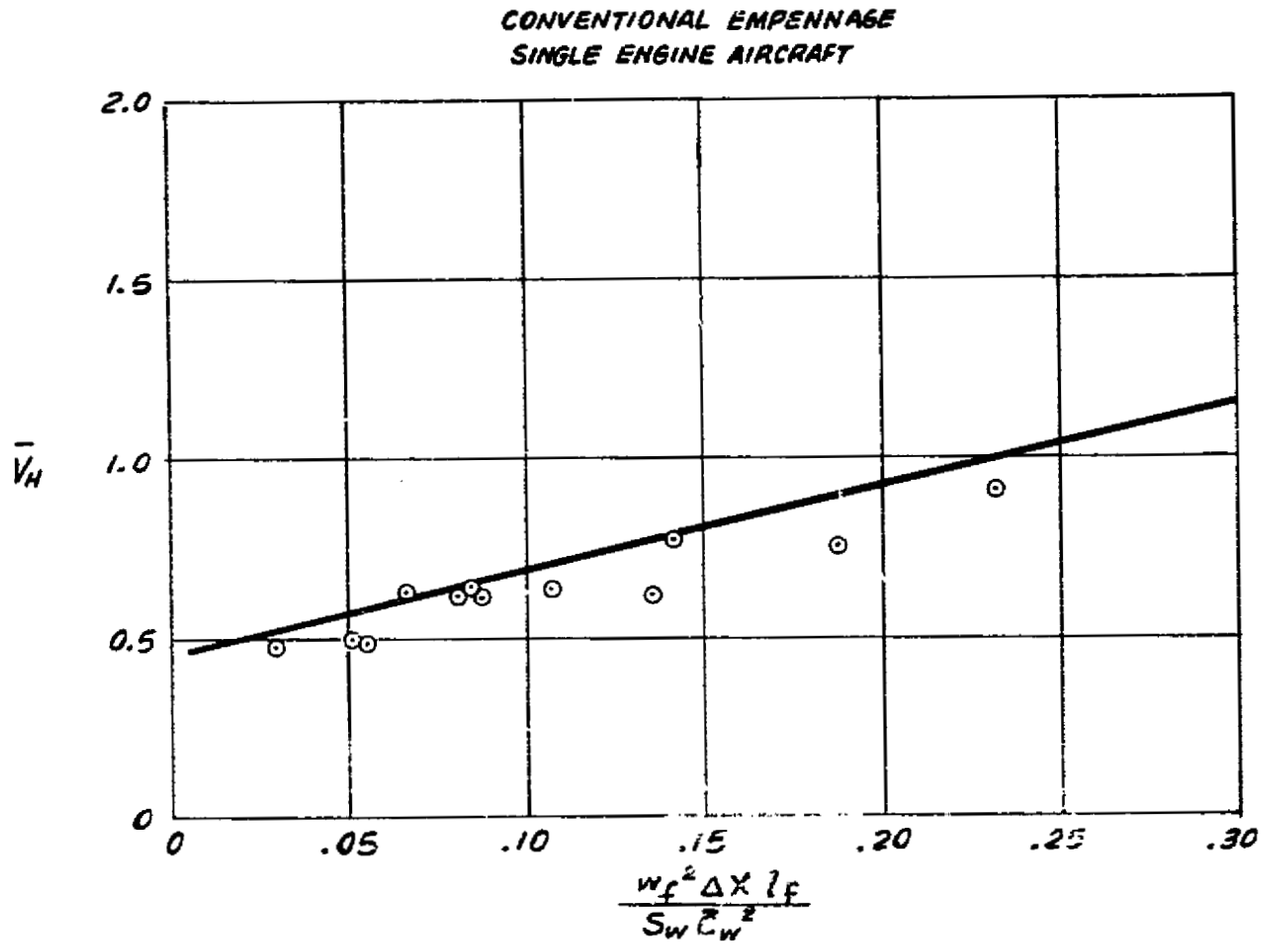


Figure 25. Correlation of Horizontal Tail Volume Coefficient with Fuselage-Wing Geometry Parameters.

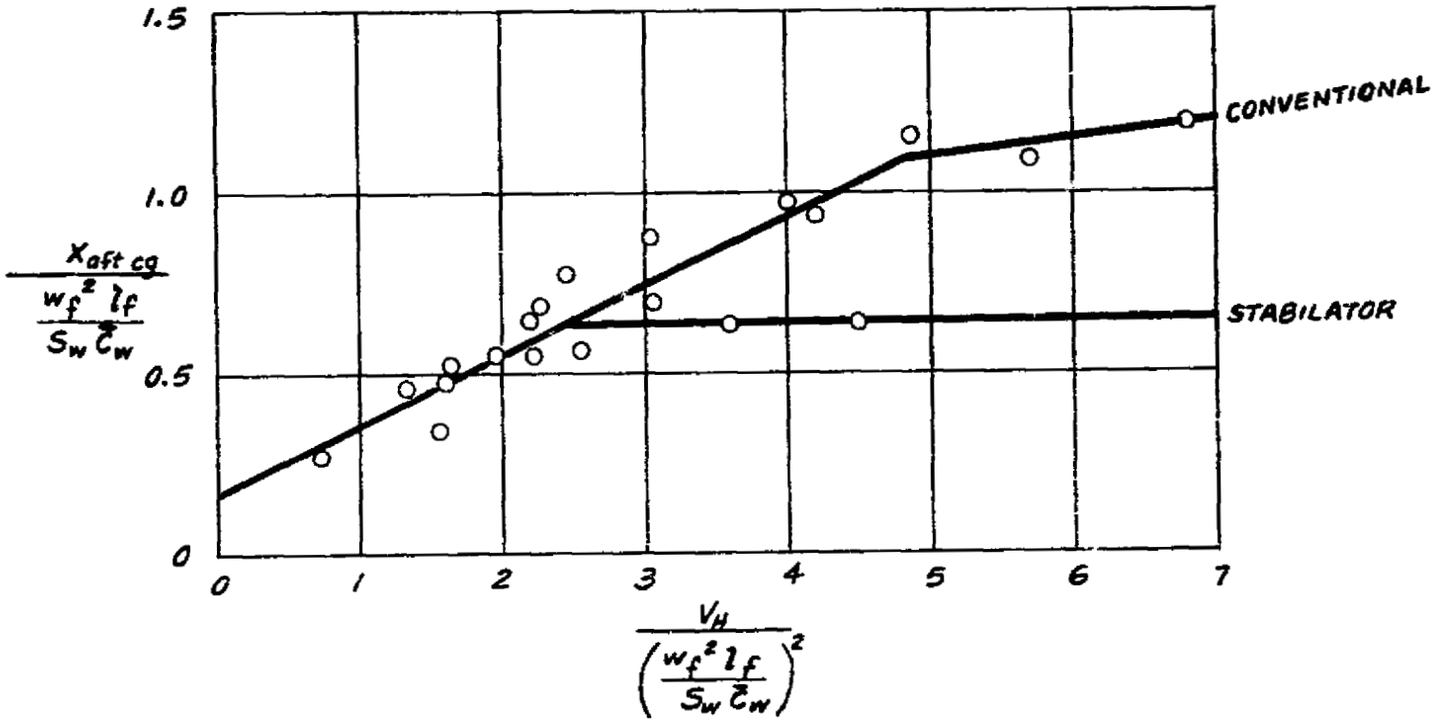


Figure 26. Correlation of Aft CG Limit with Fuselage-Wing Geometry Parameters and Tail Volume Coefficient.

3.2.6 Performance

3.2.6.1 Performance Methodology

3.2.6.1(a) Takeoff Field Length

The takeoff is considered as consisting of three parts: the ground run, transition, and climb to 50 foot height. For preliminary design work it is convenient to assume an average acceleration so that the equation for the ground run becomes

$$S_G = \frac{1}{\bar{a}_G} \int V dV$$

Where $$\bar{a}_G = g\left\{\frac{T}{W} V_{AVG} - \mu + \frac{1/2\rho S V_{AVG}^2}{W}\left[\mu C_L - C_{D_{GE}}\right]\right\}$$

Upon integration, accounting for headwinds, the ground run becomes

$$S_G = \frac{1}{2\bar{a}_G}(V_{LOF} - V_W)^2$$

where $$V_{AVG} = \left(\frac{V_{LOF}^2 + V_W^2}{2}\right)^{1/2}$$

The transition region accounts for the rotation of the flight path from horizontal to the climb gradient and acceleration to climbout speed. The transition ground distance is computed from

$$S_T = \frac{1}{\bar{a}_T} \int_{V_{LOF}}^{V_{50}} (V - V_W) dV$$

Which results in $$S_T = \frac{1}{\bar{a}_T}(V_{AVG} - V_W)(V_{50} - V_{LOF})$$

with $$\bar{a}_T = g\left\{\frac{T}{W} V_{AVG} - \frac{1/2\rho S V_{AVG}^2 C_D}{W}\right\}$$

where $$V_{AVG} = \frac{V_{50} + V_{LOF}}{2}$$

The climbout consists of a constant speed climb to 50 ft. resulting in a ground distance of

$$S_C = (V_{50} \cos\gamma)\ \frac{50 \text{ ft.}}{V_{50} \sin\gamma} = \frac{50 \text{ ft}}{\tan\gamma}$$

and $$\gamma = \sin^{-1}\left[\frac{T}{W} - \frac{1/2\rho S (V_{50})^2 C_D}{W}\right]$$

In the Cessna methodology $V_{LOF} = 1.1\ V_{Stall}$ and $V_{50} = 1.2\ V_{Stall}$. The total ground distance to clear a 50 ft. obstacle is:

$$S_G + S_T + S_C = S_{TOT_{50}}$$

3.2.6.1 (b) Methodology - Range Computation

The range of an airplane can be calculated with considerable accuracy using a time integration method if the aerodynamics, weight, engine characteristics and fuel are known. However, such methods involve considerable computational expense. To reduce this expense and eliminate the need to make a time integration to obtain the range for every payload or fuel weight desired, a modified form of the Breguet range equation is employed in the Cessna sizing program to obtain the payload range performance. The Breguet range equation was derived with the assumptions that, 1) the climb will be considered as cruise, and 2) the speed, L/D, and SFC are constant. These restrictive assumptions lead to an overestimation of range. To compensate for this a correction has been developed that reduces the initial weight by 8% of the mission fuel. This correction factor was obtained by correlation of range, estimated using Breguet's equation, with that obtained using the time integration method. It has been found to apply to both jets and reciprocating engines. This analysis was based on cruise altitudes between 7500 and 10000 ft.

3.2.6.2 Performance Justification - Takeoff Field Length

Cessna methodology for estimating takeoff field length has been compared to the actual field lengths shown in the Pilot's Operating Handbook for various aircraft. Fig. 27 shows this comparison for a range of Cessna single engine aircraft. The correlation is excellent; with variations of no more than 5% indicated.

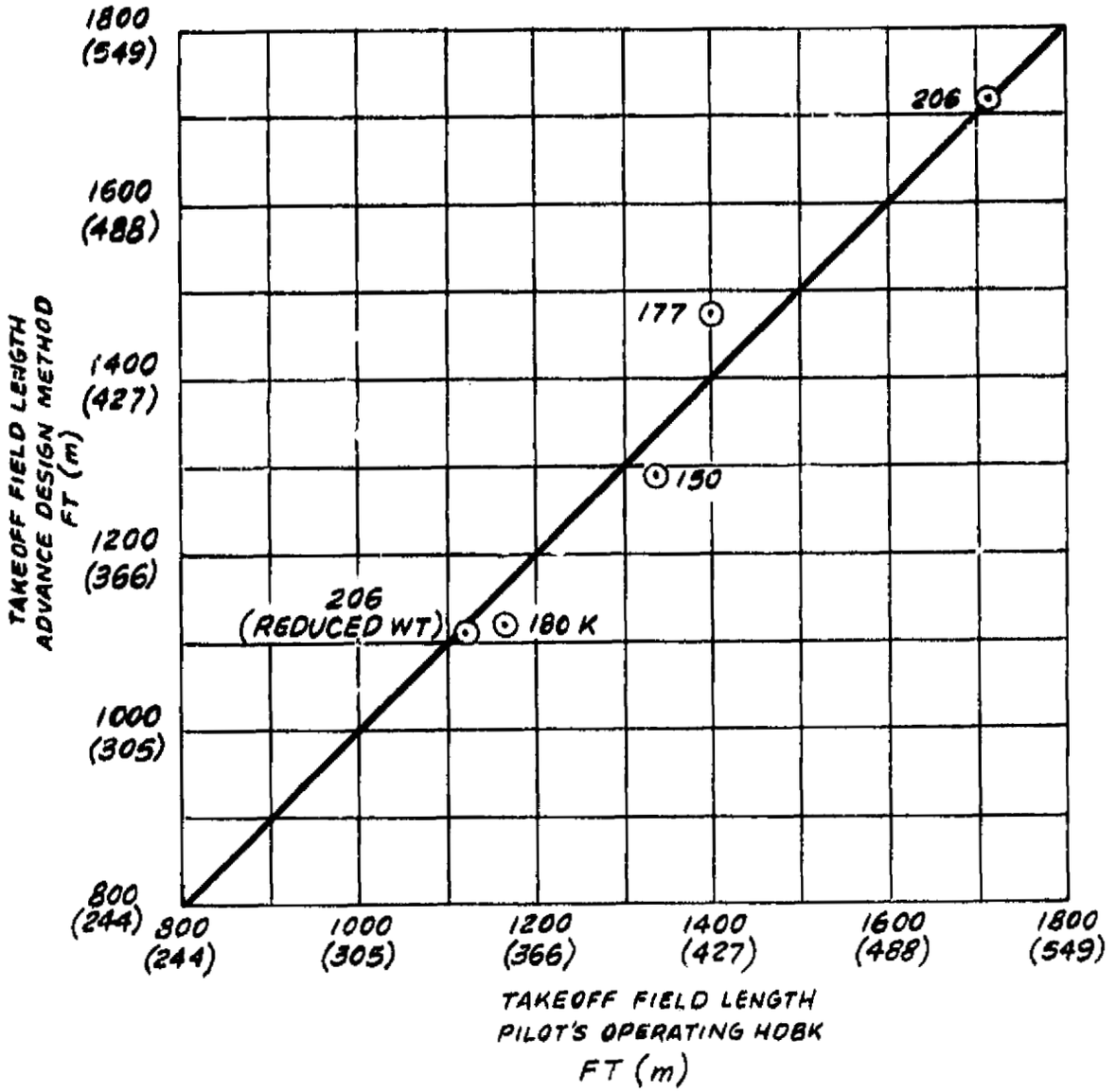


Figure 27. Takeoff Field Length Analysis.

4.0 RESULTS

4.1 GARRETT DESIGN

4.1.1 Evaluation By Cessna Methodology And Comparison To GASP Results

4.1.1.1 Lift

The maximum lift of the Garrett design (see Fig. 28 and 29) was determined using the Cessna method described in section 3.2.2. Results of this method gave a $C_{L_{MAX}}$ of 1.36 and a full flap (δ_F= 35°) maximum lift coefficient of 3.03. This produces a stall speed with full flaps of 44.2 kts at sea level. The GASP computed performance gave a $C_{L_{MAX}}$ with full flaps of 3.9? and a corresponding stall speed of 38.9 kts.

4.1.1.2 Drag

A comparison of drags as derived from Cessna's method and by Garrett using the GASP are shown on Fig.'s 30 and 31. The Garrett drags are optimistic compared to C sna's estimate. However, since Garrett did not use the form factor defaults in subroutine AERO this probably reflects their choice of inputs rather than any inherent feature in the GASP.

The Garrett values of C_{D_o} are converted into equivalent flat plate area and plotted on Fig. 32 for comparison to the Cessna estimates. They show a $C_{f_{equiv}}$ of .0045 - .0050. This is on the order of that level estimated for the Windecker Eagle, which was a cantilever wing, retractable gear aircraft with an exceptionally clean surface skin built of fiberglass. Considering that the Garrett planes are fixed gear designs it would not appear possible to achieve these low values of $C_{f_{equiv}}$.

For an example of the effect of gear on drag, compare the 177B on Fig. 32 with the 177RG. The only difference in these models is that the RG is a retractable gear version of the 177B.

4.1.1.3 Weight

The Garrett design was evaluated by the equations of section 3.2.4. The results are shown below in Table 5 along with the GASP results for comparison. For this part of the study the Garrett engine size, wing and tail areas, and gross weight were used to determine the component weights.

As can be seen the only two areas that show a significant difference are the landing gear assembly and the control system. The GASP weight estimates, in both areas, are very light compared to existing light aircraft components now in production.

4.1.1.4 Performance

The performance of two of the Garrett designs is evaluated using Cessna methods in order to compare results directly with the GASP solution. Fig.'s 33 and 34 gives the results of this comparison. In this illustration when comparing adjacent bars, the bar that ends farther to the right is considered more optimistic. For the case with Garrett input to the GASP, the GASP solution consistently gave more optimistic values than the Cessna method. In most cases the difference in the results can be explained due to the larger drag computed by the Cessna method. However, the difference in takeoff distance over 50 ft. is more than can be accounted for in this manner. The Cessna advance design method for takeoff performance is outlined and substantiated in section 3.2.6.

GARRETT 2-PLACE TRAINER DESIGN

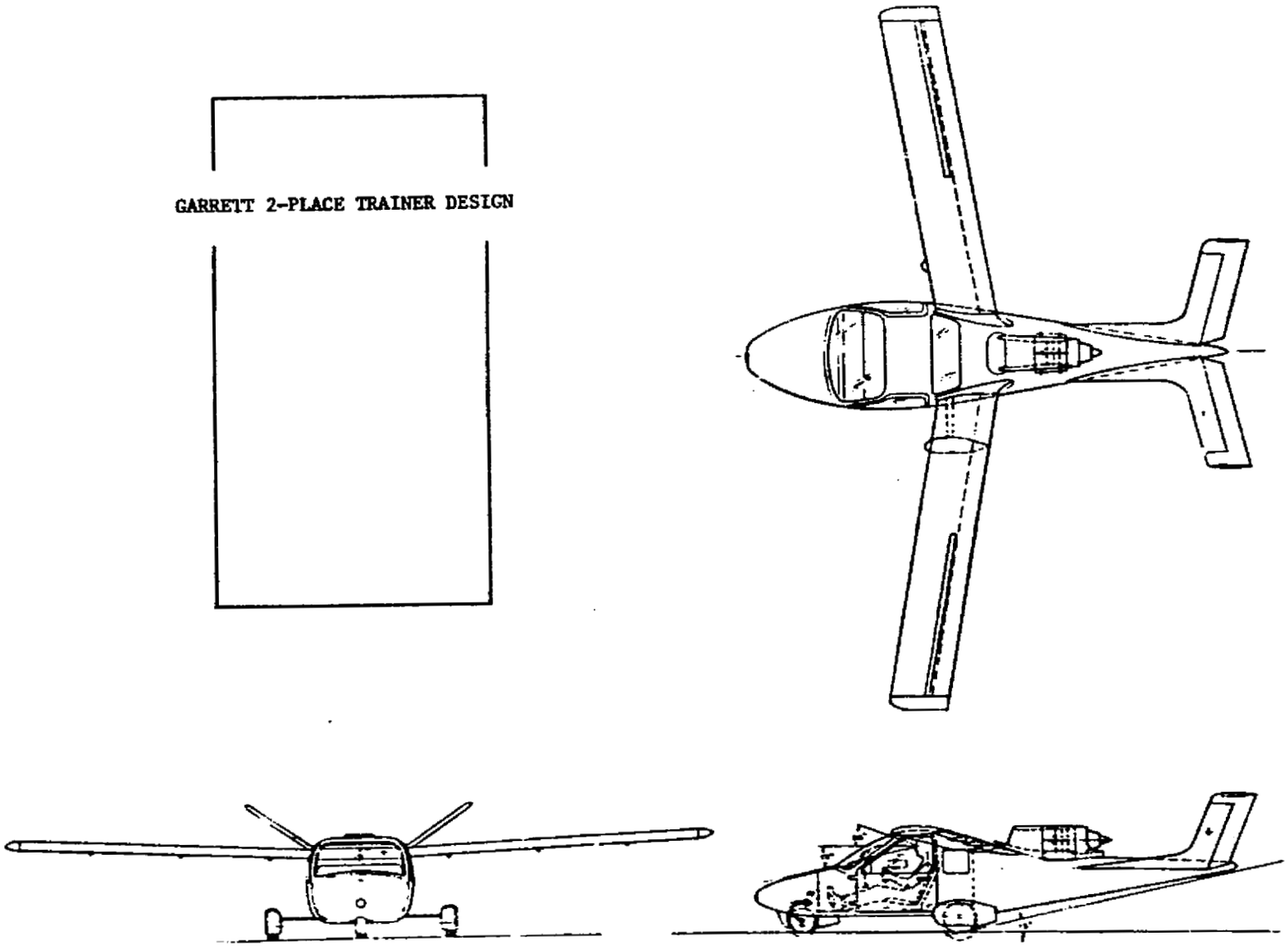


Figure 28. Garrett 2-Place Trainer Design

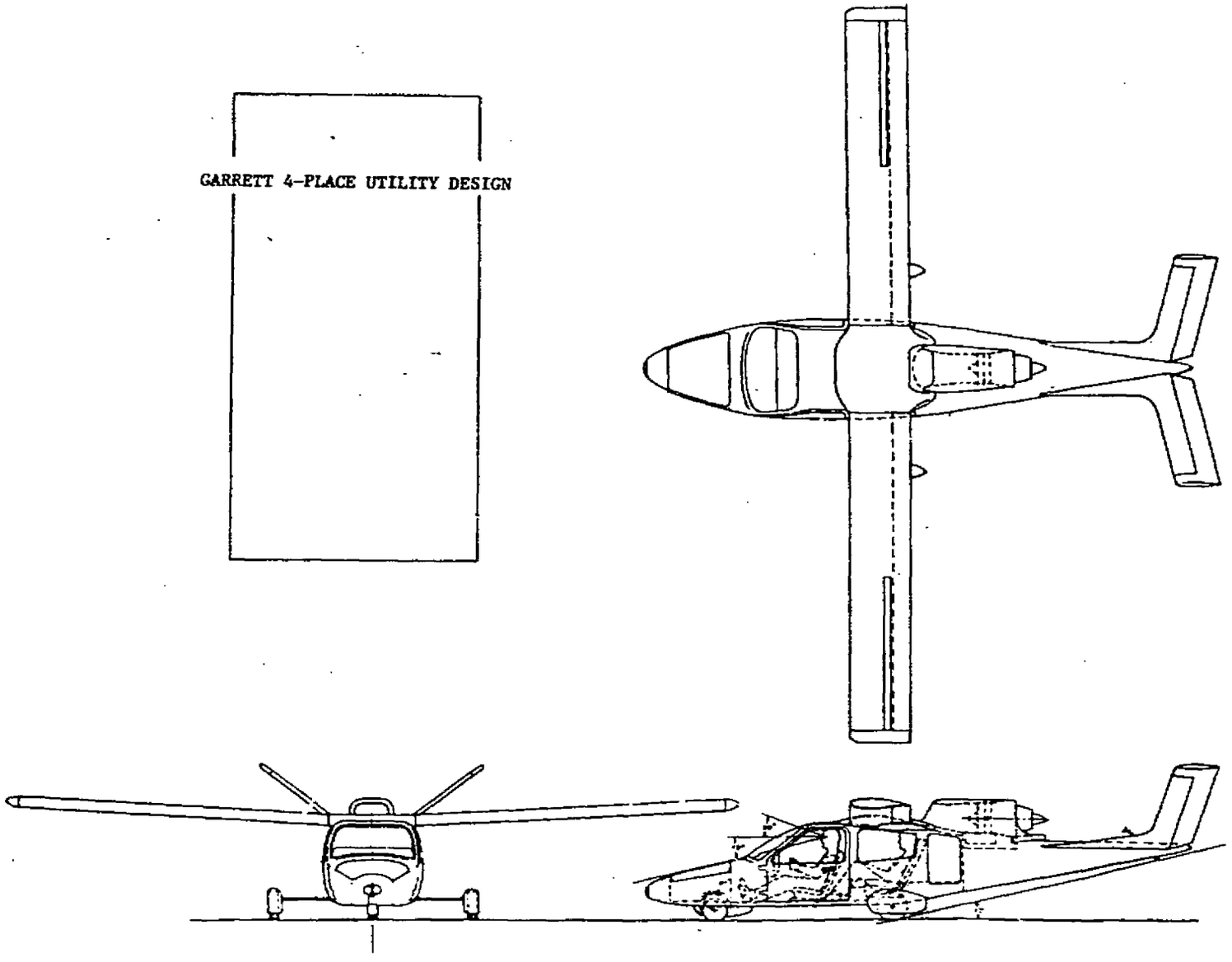


Figure 29. Garrett 4-Place Utility Design

Figure 30

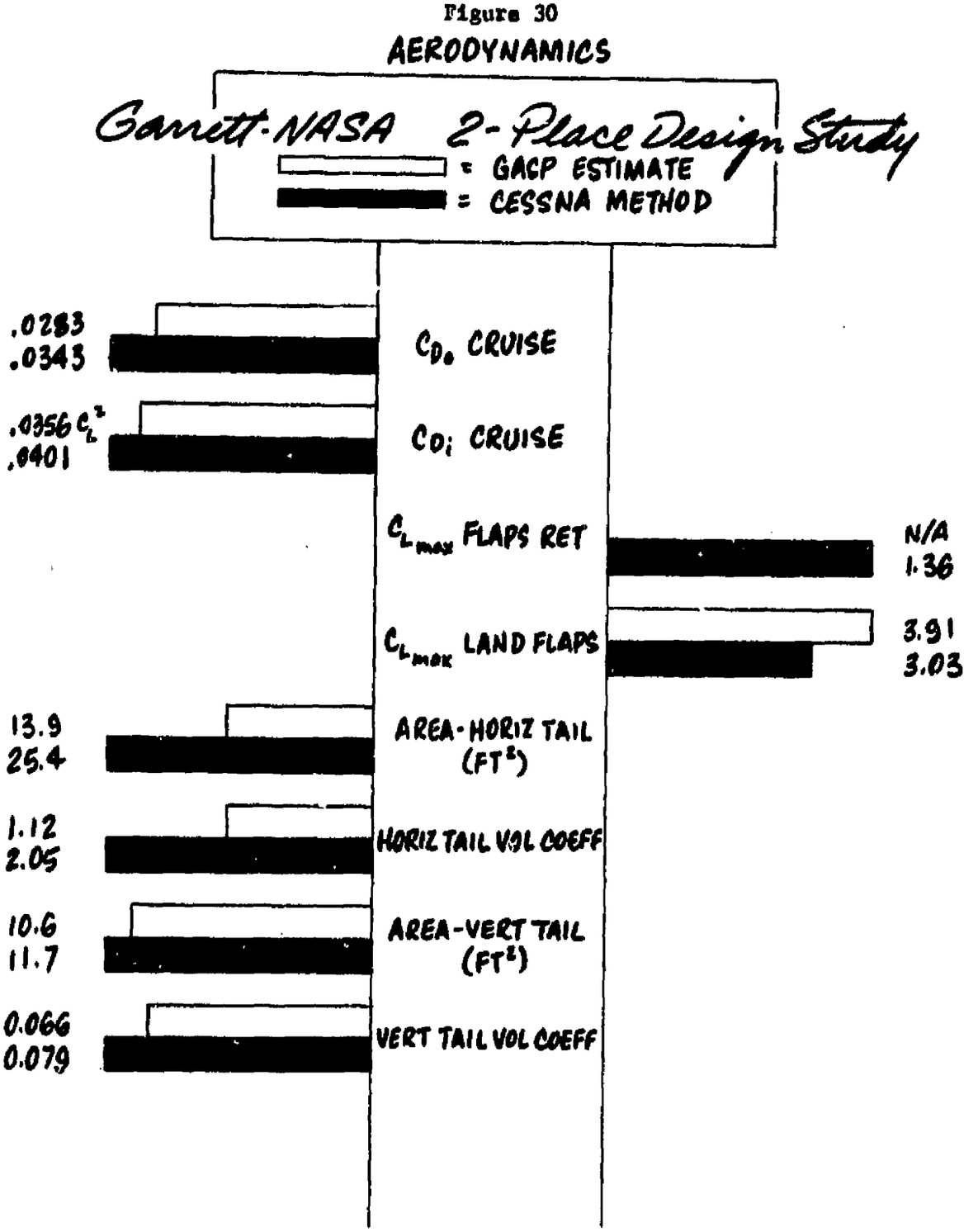
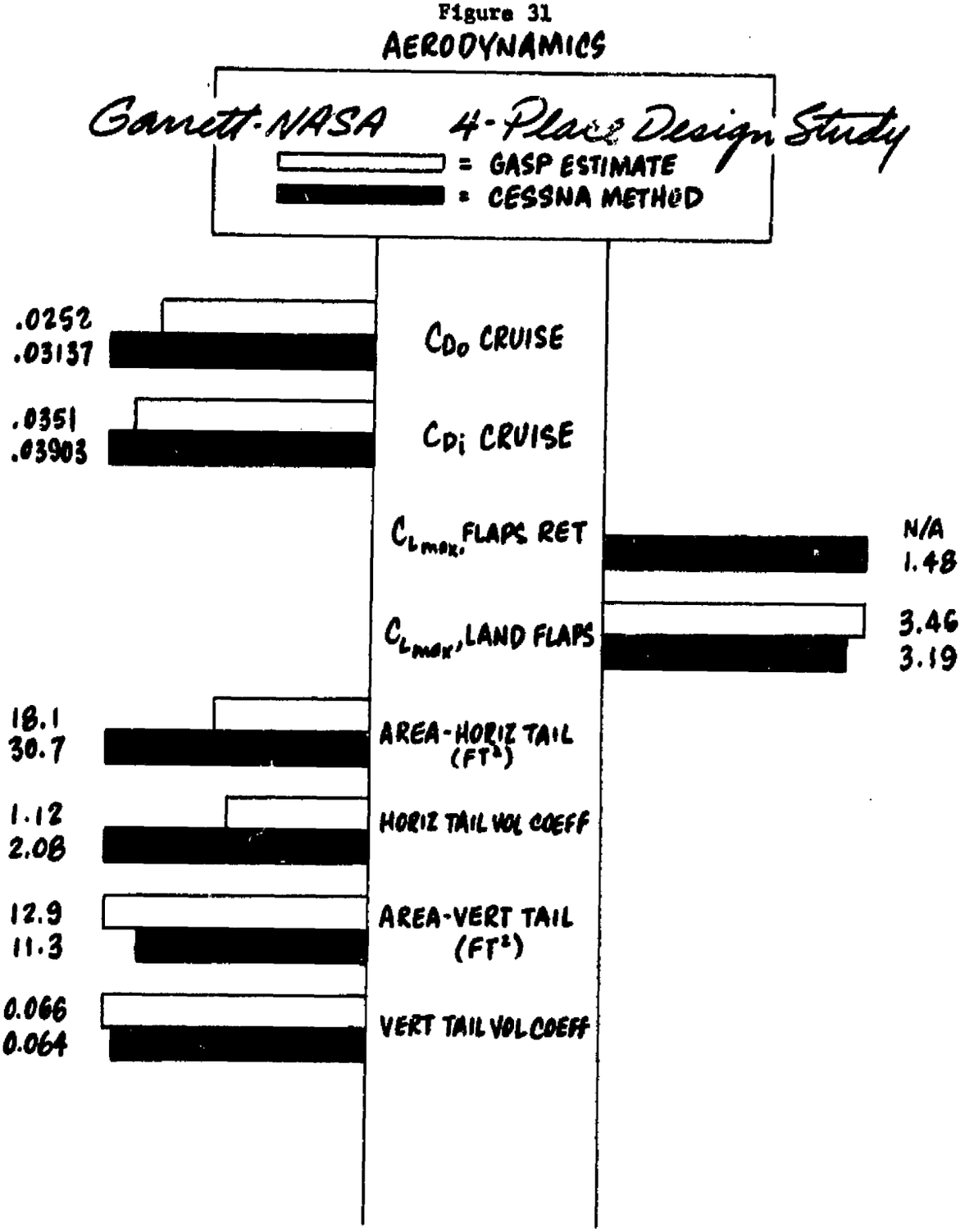

AERODYNAMICS
Garrett-NASA 2-Place Design Study
= GACP ESTIMATE
= CESSNA METHOD
.0283
.0343
C_{D_o} CRUISE
.0356 C_L^2
.0401
C_{D_i} CRUISE
$C_{L_{max}}$ FLAPS RET
N/A
1.36
$C_{L_{max}}$ LAND FLAPS
3.91
3.03
13.9
25.4
AREA-HORIZ TAIL (FT^2)
1.12
2.05
HORIZ TAIL VOL COEFF
10.6
11.7
AREA-VERT TAIL (FT^2)
0.066
0.079
VERT TAIL VOL COEFF

Figure 31


AERODYNAMICS
Garrett-NASA 4-Place Design Study
= GASP ESTIMATE
= CESSNA METHOD
.0252
.03137
C_{D_o} CRUISE
.0351
.03903
C_{D_i} CRUISE
$C_{L_{max}}$, FLAPS RET
N/A
1.48
$C_{L_{max}}$, LAND FLAPS
3.46
3.19
18.1
30.7
AREA-HORIZ TAIL (FT²)
1.12
2.08
HORIZ TAIL VOL COEFF
12.9
11.3
AREA-VERT TAIL (FT²)
0.066
0.064
VERT TAIL VOL COEFF

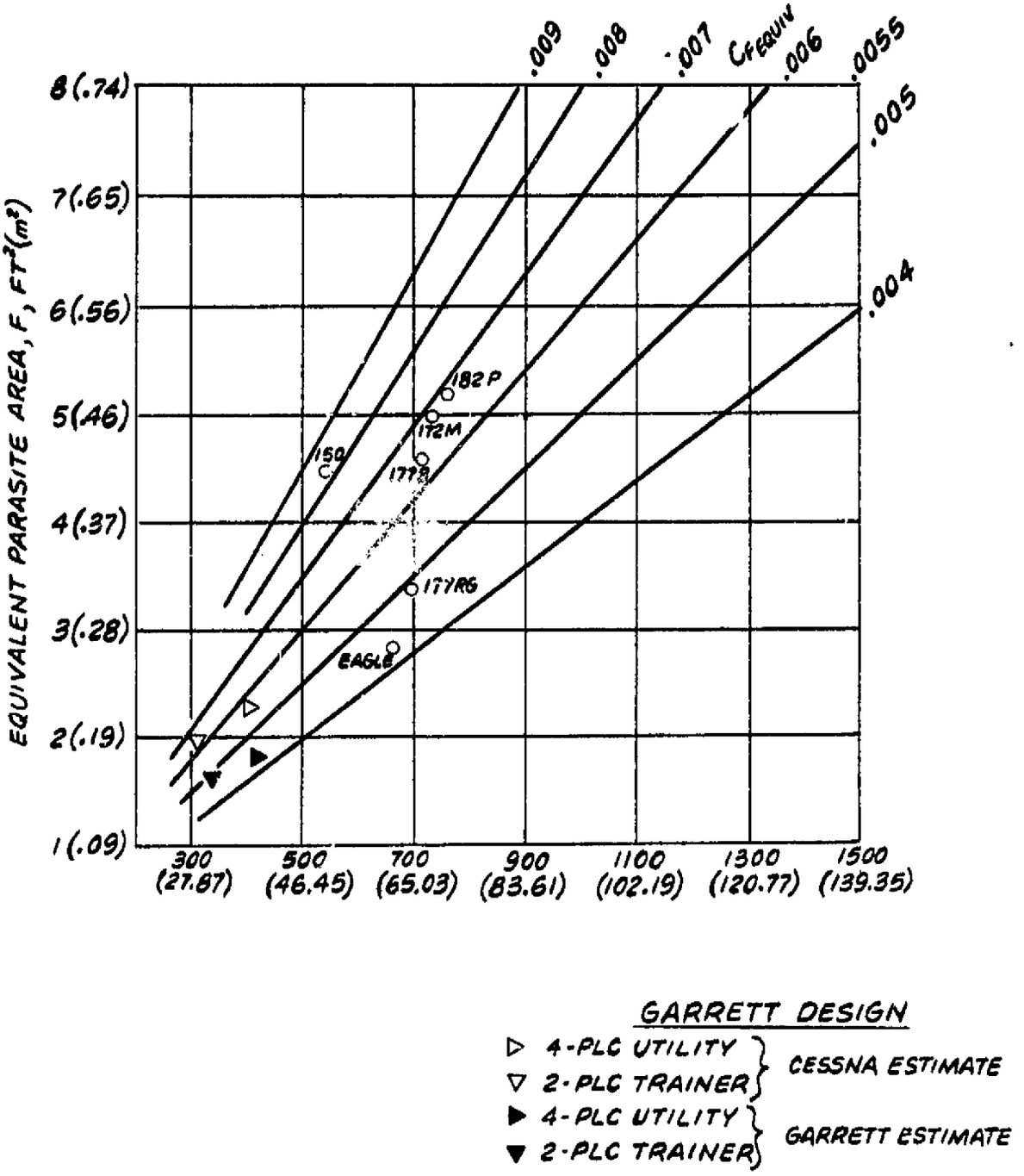


Figure 32. Comparison of Estimated Drag Levels for Garrett's Configurations.

TABLE 5

EVALUATION OF THE WEIGHT STATEMENT OF THE GARRETT 2-PLACE TRAINER

ITEM	CESSNA		GASP
Wing		130.3	135.0
Fuselage		127.6	128.0
Powerplant Instl.		61.0*	61.0*
Nacelle		9.9	7.0
Vertical Tail (Projected)	13.6		
Horizontal Tail (Projected)	13.1	26.7	27.0
Main Gear Assys.	50.0		
Nose Gear Assy	26.0	76.0	50.0
Control System		40.0	24.0
Equipment	46.6		
Furnishings	80.0	126.6	132.0
Empty Weight		595.1	564.0
Oil		1.9	-
Occupants		340.0	340.0
Baggage		60.0	60.0
Fuel To Gross		160.0	196.0
Gross Weight		1160.0*	1160.0*

*Garrett supplied value

Figure 33

PERFORMANCE

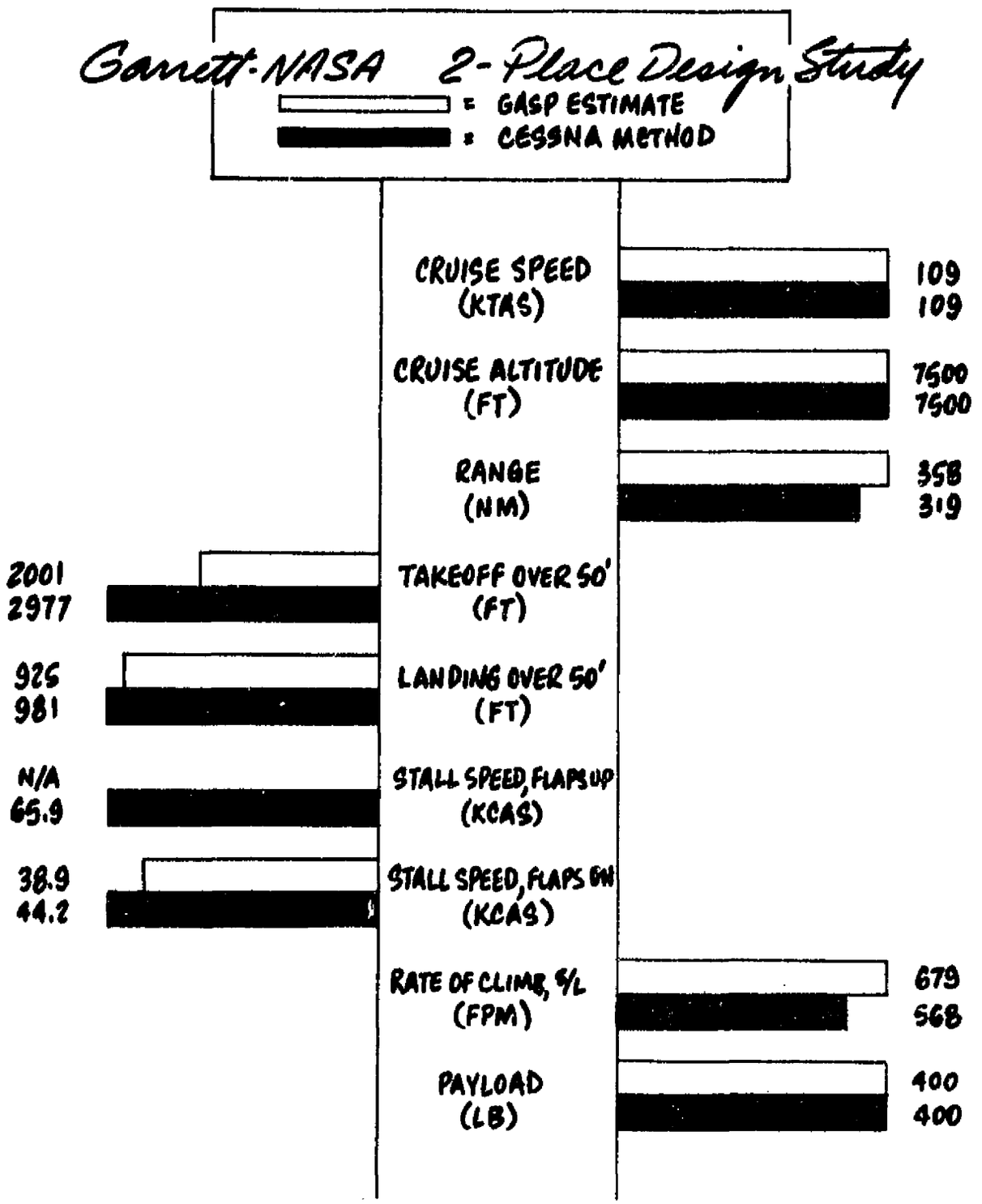
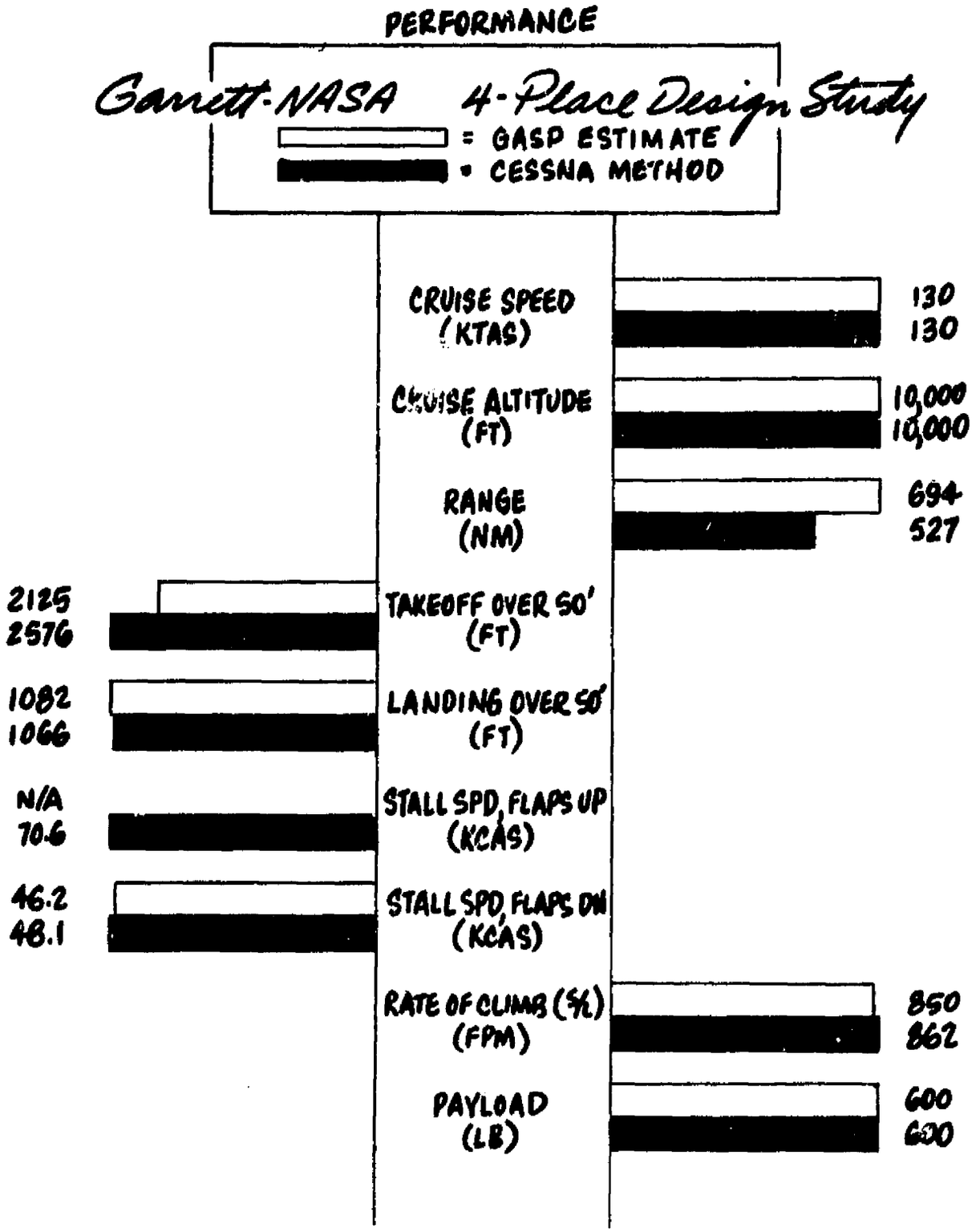


Figure 34


PERFORMANCE
Garrett-NASA 4-Place Design Study
= GASP ESTIMATE
• CESSNA METHOD
CRUISE SPEED (KTAS)
130
130
CRUISE ALTITUDE (FT)
10,000
10,000
RANGE (NM)
694
527
TAKEOFF OVER 50' (FT)
2125
2576
LANDING OVER 50' (FT)
1082
1066
STALL SPD, FLAPS UP (KCAS)
N/A
70.6
STALL SPD, FLAPS DN (KCAS)
46.2
48.1
RATE OF CLIMB (SL) (FPM)
850
862
PAYLOAD (LB)
600
600

4.1.2 Comments On The Garrett Design

4.1.2.1 Wing, Engine, Gear Design

In order to complete this critique, the following comments are offered, which deal with some of the design features of the Garrett plane.

The untapered wing planform may appear to offer real cost savings by reducing the number of different rib designs of a tapered planform down to one and allowing various other simplifications in flap and aileron design. However, close examination of the spar design will show that important weight savings can be realized by using a modified "I" shaped spar and by tapering it along the span. Since the ribs attach to the spar, the same rib cannot be used along the entire span regardless of planform. Therefore, very little real savings accrue and the better aerodynamic efficiency and aesthetics of a tapered planform dictate its use.

The gear design shown by Garrett would have to be exceptionally stiff to keep from bottoming the fuselage during a hard landing. Landing with such a stiff gear would be both difficult and unpleasant.

The engine appears to be located too far aft. As discussed in section 3.2.1.1 this leads to an unacceptably large cg travel between light and heavy payloads. In addition, the inlet is behind the high wing; which means that the disturbed flow off the wing fuselage juncture, during a stall, would probably be ingested by the engine It seems unlikely that the engine could continue to run under such circumstances. Finally, the exhaust of a jet always entrains air into itself. Since this exhaust passes between the V-tail units, the entrained air induces a greater positive angle of attack on the tail as the thrust is increased. This indirect thrust effect may be as large or larger than the direct thrust pitching moment and will be felt by the pilot as a large trim change with power.

4.1.2.2 Tail Design

The V-tail chosen by Garrett is not usually used in general aviation (with one notable exception). At first it appears possible to save weight and wetted area by using this type tail. A careful analysis of the problem, however, shows that almost all of the savings are illusory - very little if any area is saved. In a preliminary design, before wind tunnel data is available, a good design practice is to size the V-tail to have the same total area as the conventional tail it replaces. For this reason alone Garrett's tail appears small.

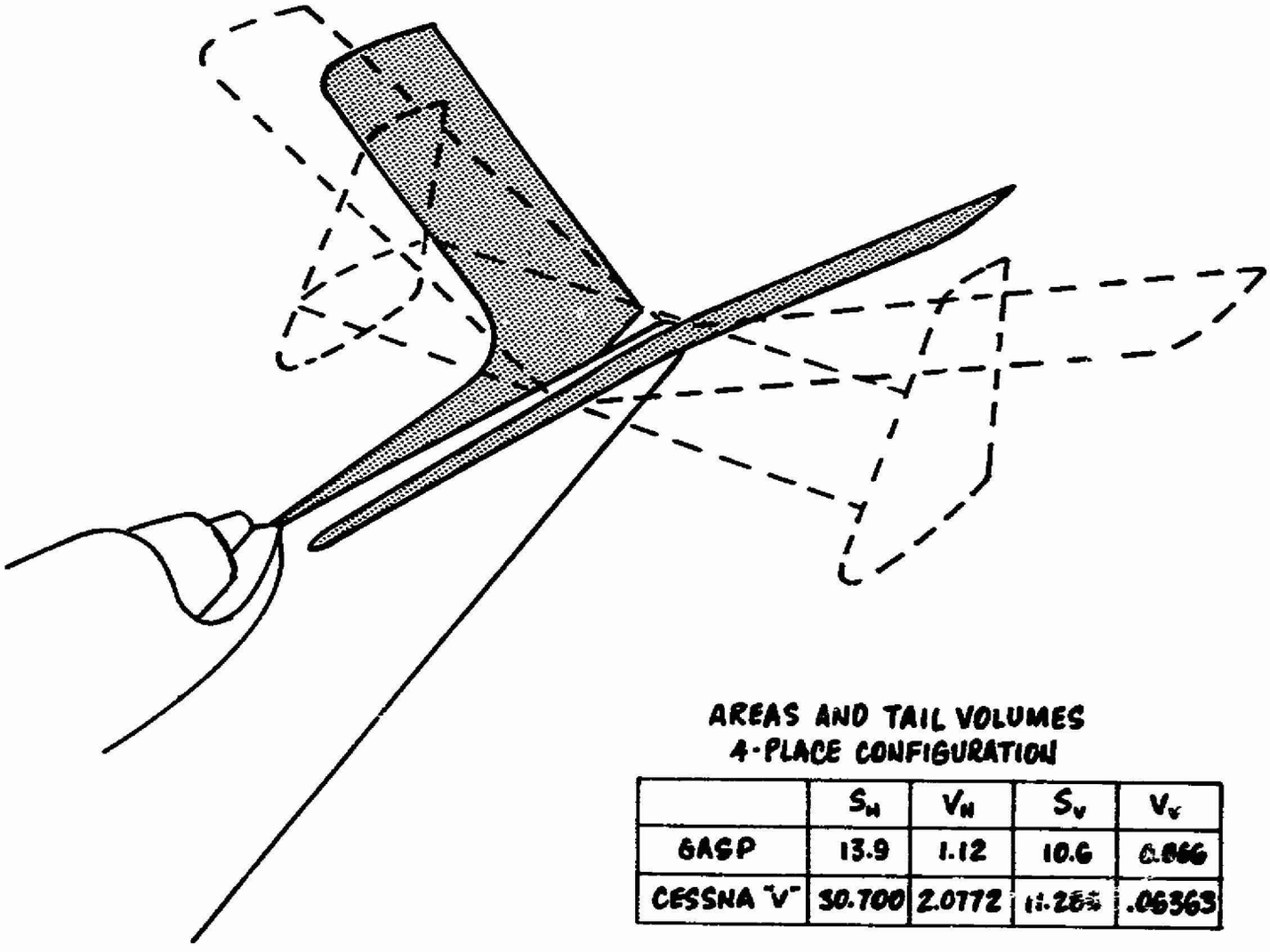
Secondly, the high aspect ratio wing used by Garrett has a very small chord; and, therefore, a large cg range in percent chord. Consequently the plane needs a large tail. Since the GASP does not estimate cg range nor modify the tail size with cg range, the tail again appears to be small.

Using the Cessna trend equations from section 3.2.5.1 the tail size requirement for the Garrett planes was estimated. (An assumption was made that the engine could be moved to bring the aft cg within acceptable limits.) These

areas are shown on Fig.s 30 and 31 of section 4.1.1.2. Schematically, a comparison is shown in Fig. 35 between the Garrett sized tail (shaded) and the Cessna designed V-tail.

Obviously the Cessna V-tail is so large and the angle between the surfaces so great, that it is impractical. A rough estimate showed that the rolling moment due to rudder, for example, would be as large as the yawing moment.

A more reasonable approach is indicated on Fig. 35 in the form of a conventional horizontal with twin verticals. Although the total vertical tail area of this design is larger than for a single tail, there is an equivalent or larger savings in the area of the horizontal tail due to the end plating effects of the verticals. This design provides a more plausible solution than the V-tail when, because of the jet efflux, a conventional empennage is impractical.



AREAS AND TAIL VOLUMES
4-PLACE CONFIGURATION

	S_H	V_H	S_V	V_V
GASP	13.9	1.12	10.6	0.066
CESSNA "V"	30.700	2.0772	11.28	.06363

Figure 35. Tail Size Analysis

4.2 PHASE III - WING OPTIMIZATION FOR BASELINE

4.2.1 By Cessna Methodology

The Cessna sizing method makes use of relationships derived from the methodologies of sections 3.2.2 thru 3.2.5. These relationships include BEW = f(W, S_W), tail size = f(wing area, wing chord, etc.) and drag = f (wetted area.) Wetted area, of course, varies with the wing and tail areas. These relationships are used to evaluate the influence of the design parameters on aircraft size.

The main sizing program reads in a data set which consists, in part, of a matrix of design parameters, (such as AR, wing area, engine size, etc.) This program then calls various subroutines that, for each point in the matrix, iterate on the weight to obtain a particular performance parameter (TOFL = 1700, V_S = 50 kts. etc.) The performance parameters are set by the design requirements (see section 3.1.1.)

The routines, for the most part, utilize straightforward, iteration and performance methods. Some explanation, however, is required for the subroutine that sizes the plane for the payload-endurance.

For reciprocating powered aircraft, the maximum cruise power is set by considerations of engine operating characteristics at a value between 75 and 80 percent of the rated horsepower. For a given cruise altitude this of course sets the speed.

For turbofans no similar constraint exists for setting the engine thrust. Some logical rationale for setting thrust must, therefore, be developed. Logically, the pilot would like to cruise at the speed for maximum range and the decision was made to set the throttle to give this speed.

In order to accomplish this, one more iteration loop that maximizes range is required in the payload-endurance sizing routine. Fig. 36 illustrates the procedure used in the Cessna methodology to determine the aircraft weight which will satisfy the given payload-endurance. Fig. 37 shows a characteristic sizing plot produced by the sizing program for the light turbofan aircraft. At a constant aspect ratio, taper ratio, thickness ratio, and engine rating the minimum weight aircraft that will satisfy all of the design requirements can be determined from this figure. The wing parameters of aspect ratio, thickness ratio, and taper ratio were varied as shown in Table 3, section 3.2.1.2 and some of the results are shown in Table 6. At each of the sized points the direct operating cost was calculated using the Cessna direct operating cost methods and a result at one taper ratio is shown in Fig. 38. Based upon the results of this study a wing geometry selection was made.

It was found that the taper ratio had a negligible effect upon both the weight and the cost and, therefore, based on stability and control requirements (roll damping, stall characteristics, down wash gradient, lateral stability) and aesthetic appeal the wing taper ratio was set at 0.75.

From an average thickness of .13 to .15 the DOC remained virtually unchanged, showing a significant rise only when $t/c)_{avg}$ rose to .17. Therefore, to lessen the structural design difficulties a $t/c)_{avg}$ = .15 was chosen. $(t/c)_r$ =.17, $t/c)_t$= .13).

As was illustrated in Fig. 38 the Cessna methods indicated that as aspect ratio was decreased the direct operating cost was decreased in the range of aspect ratios investigated. However since there is very little variation in DOC from AR=6 to AR=8, the aesthetics of the vehicle and the interference of the cabin door with the wing at lower aspect ratios were considered and an aspect ratio of 7.5 was selected.

Table 6 and Fig. 38 were generated before an error was discovered in one of Cessna's sizing routines. Such error effected only the variation of DOC with aspect ratio and the corrected curve is indicated in Fig. 39. This shows that minimum DOC (.3255 $/N Mi) occurs around AR=6.3 and the choice of an AR=7.5 wing (DOC = .3263 $/N Mi) was valid.

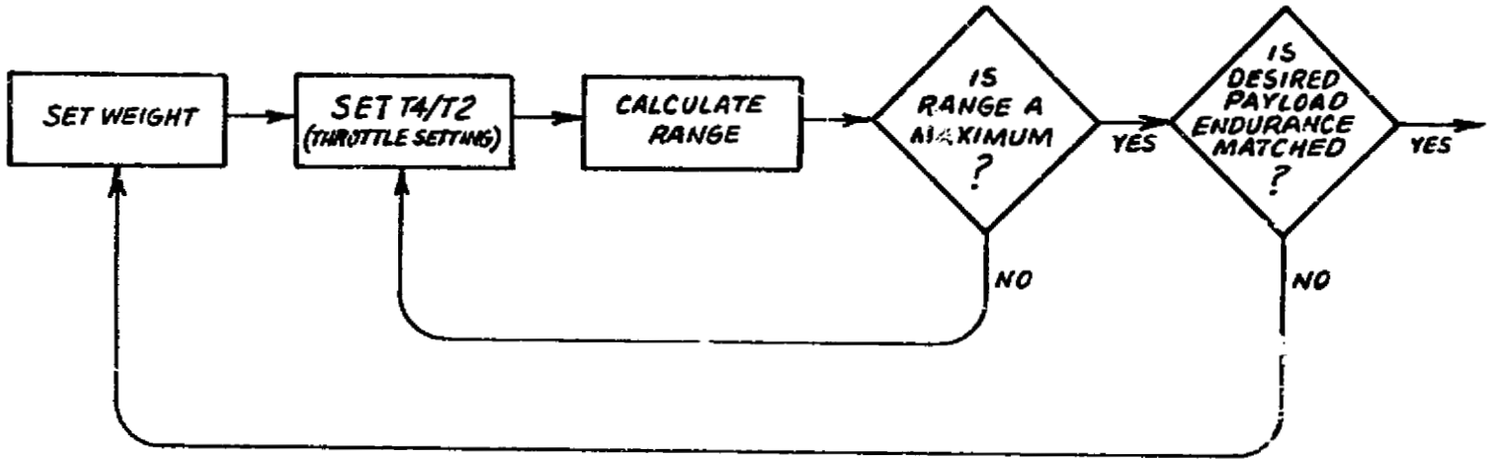


Figure 36. Schematic of Cessna's Method for Determining Payload-Range at Maximum Range Speed.

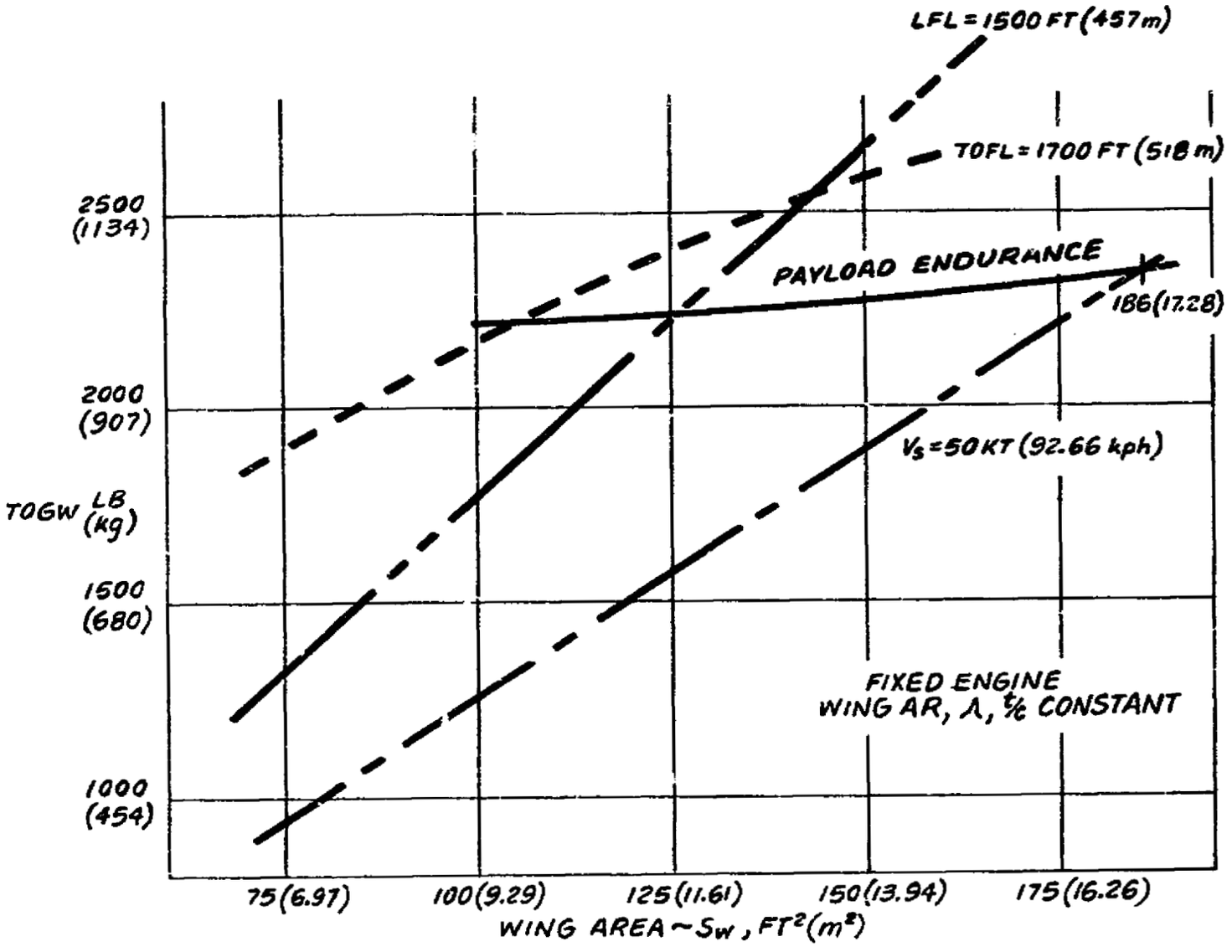


Figure 37. Wing Sizing, Cessna Methodology.

TABLE 6

WING GEOMETRY OPTIMIZATION
RESULTS

AR	t/c(%) root	λ	GW(LB)	SW(FT^2)
6	15	.75	2220	169
	17		2200	170
	19		2180	172
9	15		2380	186.5
	17	.50	2340	185
		.75	2340	186
		1.00	2360	188
	19	.75	2320	187.5
12	15		2700	215
	17		2640	212.5
	19		2580	210

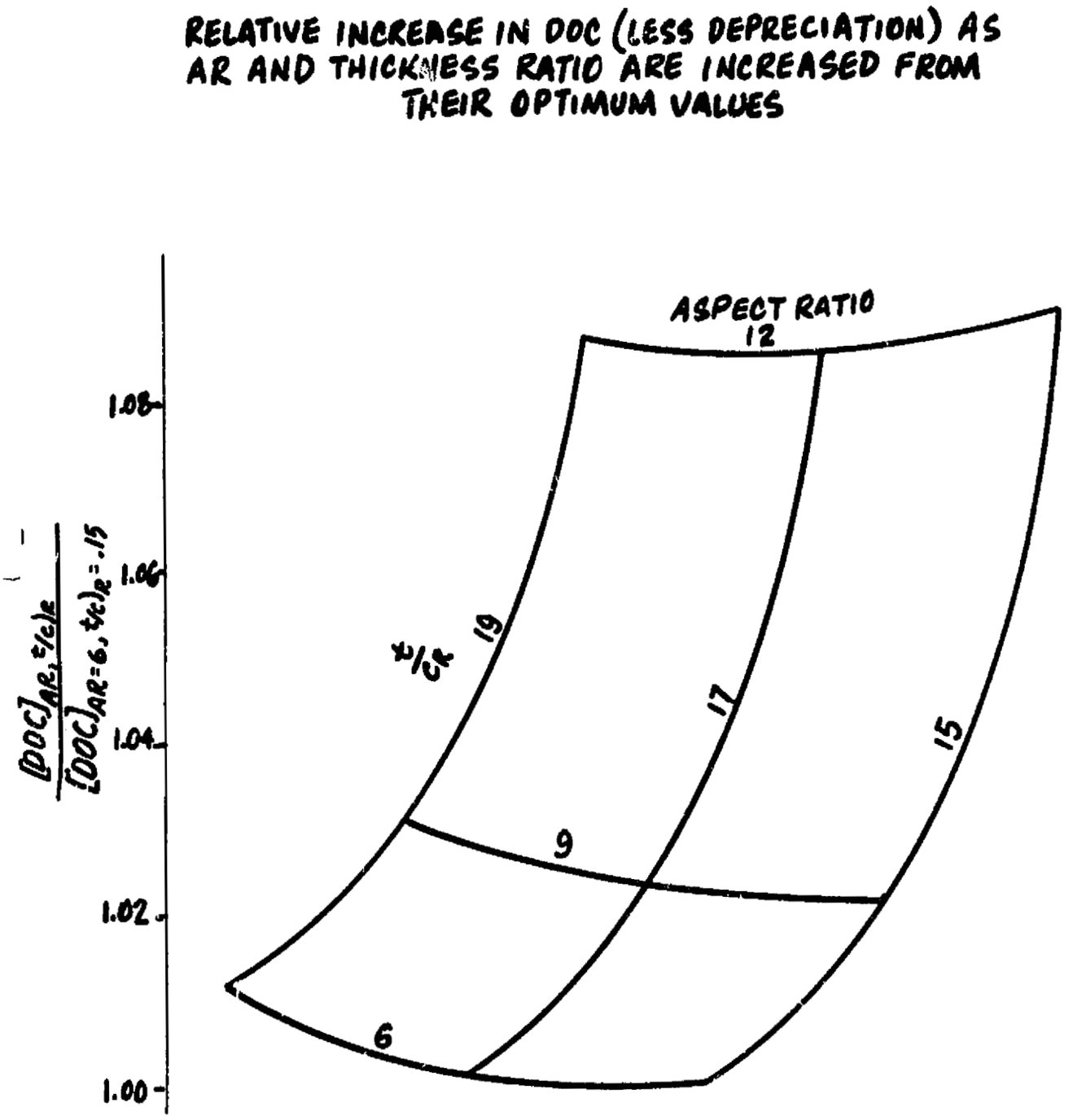


Figure 38. Wing Geometry Optimization, Cessna Methodology.

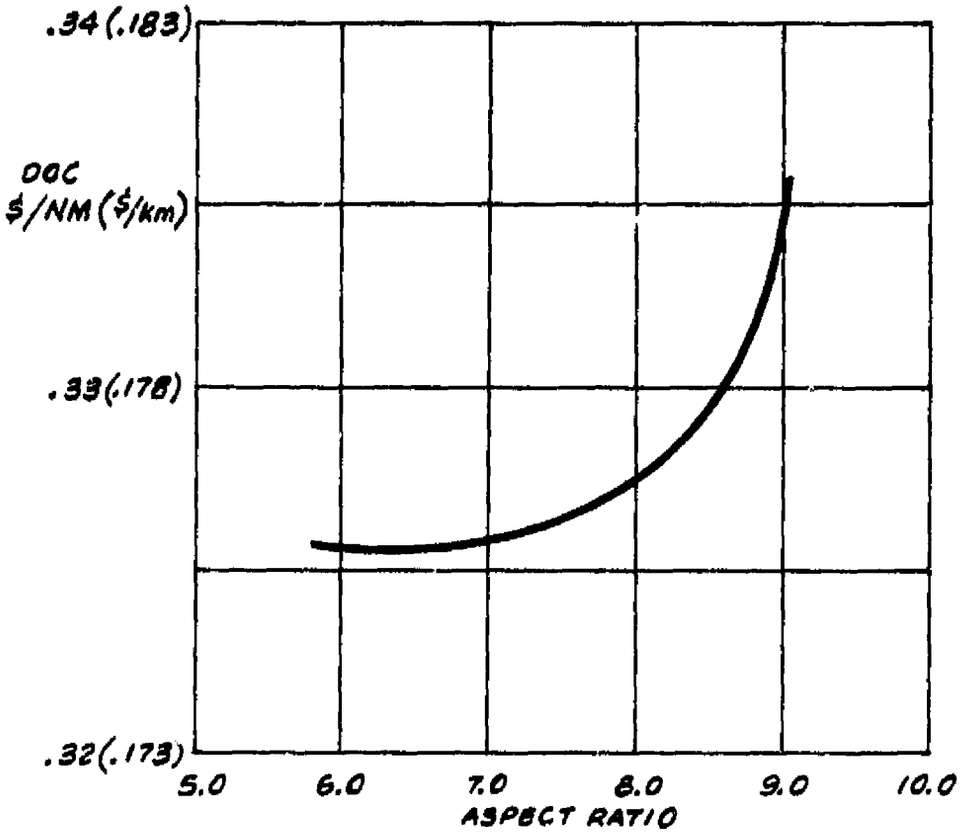


Figure 39. Effect of Aspect Ratio on Operating Economics-Final Analysis.

4.2.2. Wing Optimization by GASP

When this study was originally formulated, the plans called for duplicating the wing geometry optimization procedure done in the previous section by a similar analysis using GASP.

GASP, as now written, is not capable of directly optimizing cruise speed for maximum range (see section 4.2.1). It can, in one run, analyze only one cruise speed. The process by which it may be done is outlined and illustrated in section 4.3.2 where the engine size is optimized. This procedure is long and tedious. In order to have a valid comparison between the GASP and Cessna's methods the ground rules must be the same, i. . there is no possible short cut such as picking a constant cruise speed for the GASP analysis.

It was impractical from a time and budget standpoint to use this procedure on the large wing geometry matrix that was analyzed in section 4.2.1. Therefore, the GASP analysis was not done and the optimum wing geometry derived by Cessna's methodology in section 4.2.1 was used for the engine optimization analysis.

4.3 PHASE IV - ENGINE OPTIMIZATION FOR BASELINE

4.3.0 Reconciliation of Method

In comparing sizing results obtained from the GASP to those obtained from the Cessna methodology, it should be noted that the sea level static thrust quoted by GASP is an installed level and that quoted by the Cessna method is uninstalled. This difference results from the manner by which installation losses are treated by each program.

4.3.1 By Cessna Methodology

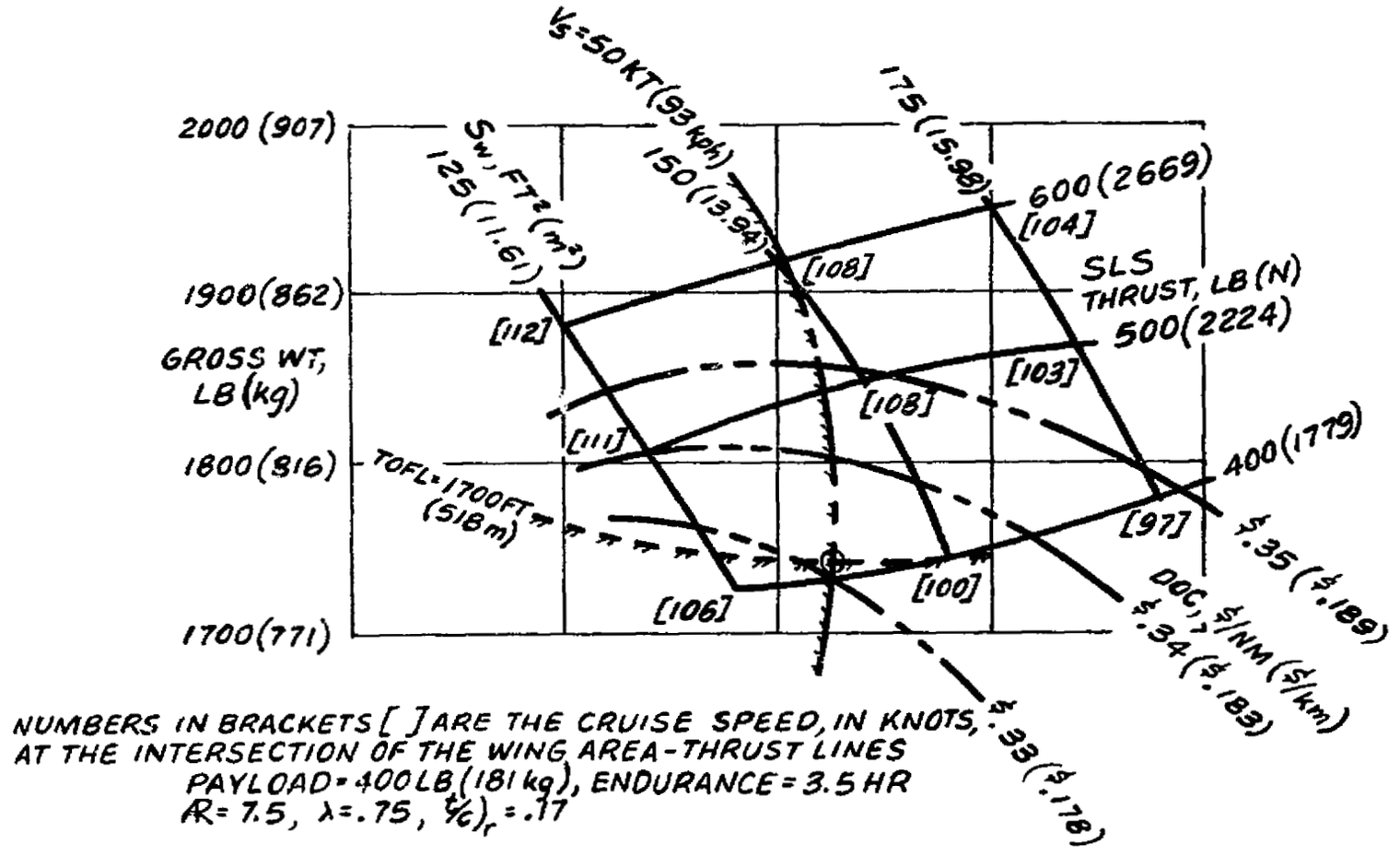
With the wing geometry parameters determined during the wing optimization, (section 4.2.1), a matrix of engine ratings (SLST) and wing areas was analyzed by the sizing program and the results were plotted on the carpet plot of Fig. 40. This figure represents all configurations that will satisfy the requirement of 3.5 hours endurance with 400 pounds of payload. Cross plotted in this figure are the takeoff field length requirement and stall speed requirement and lines of constant direct operating cost. The configuration which satisfies all of the design requirements and has the minimum direct operating cost is represented by the intersection of the TOFL line and the V_S line at a weight of 1740 lb., a wing area of 137.3 ft^2, and engine rating of 415 lb. The direct operating cost at this point is .332 $/nm. This configuration, shown in Fig. 41 incorporates the optimum sized wing and engine in order to satisfy the design requirements specified in Table 2 of section 3.1.1 at the minimum direct operating cost.

Fig. 42 shows the loading envelope for this final sized airplane. The aft cg is defined by the minimum flying weight and the entire useful load is forward of this. The loading envelope is defined between the forward cg of 17.6% and the aft cg of 32.3%.

The design payload of 400 lb* is capable of being loaded with full fuel (337 lb).

The drag levels used in this sizing study are shown on Fig. 43.

*Includes NAVCOM and transponder



NUMBERS IN BRACKETS [ ] ARE THE CRUISE SPEED, IN KNOTS, AT THE INTERSECTION OF THE WING AREA-THRUST LINES
PAYLOAD = 400 LB (181 kg), ENDURANCE = 3.5 HR
$AR = 7.5$, $\lambda = .75$, $(t/c)_r = .17$

Figure 40. Final Sizing Plot for the 2-Place Trainer. From Cessna's Sizing Program.

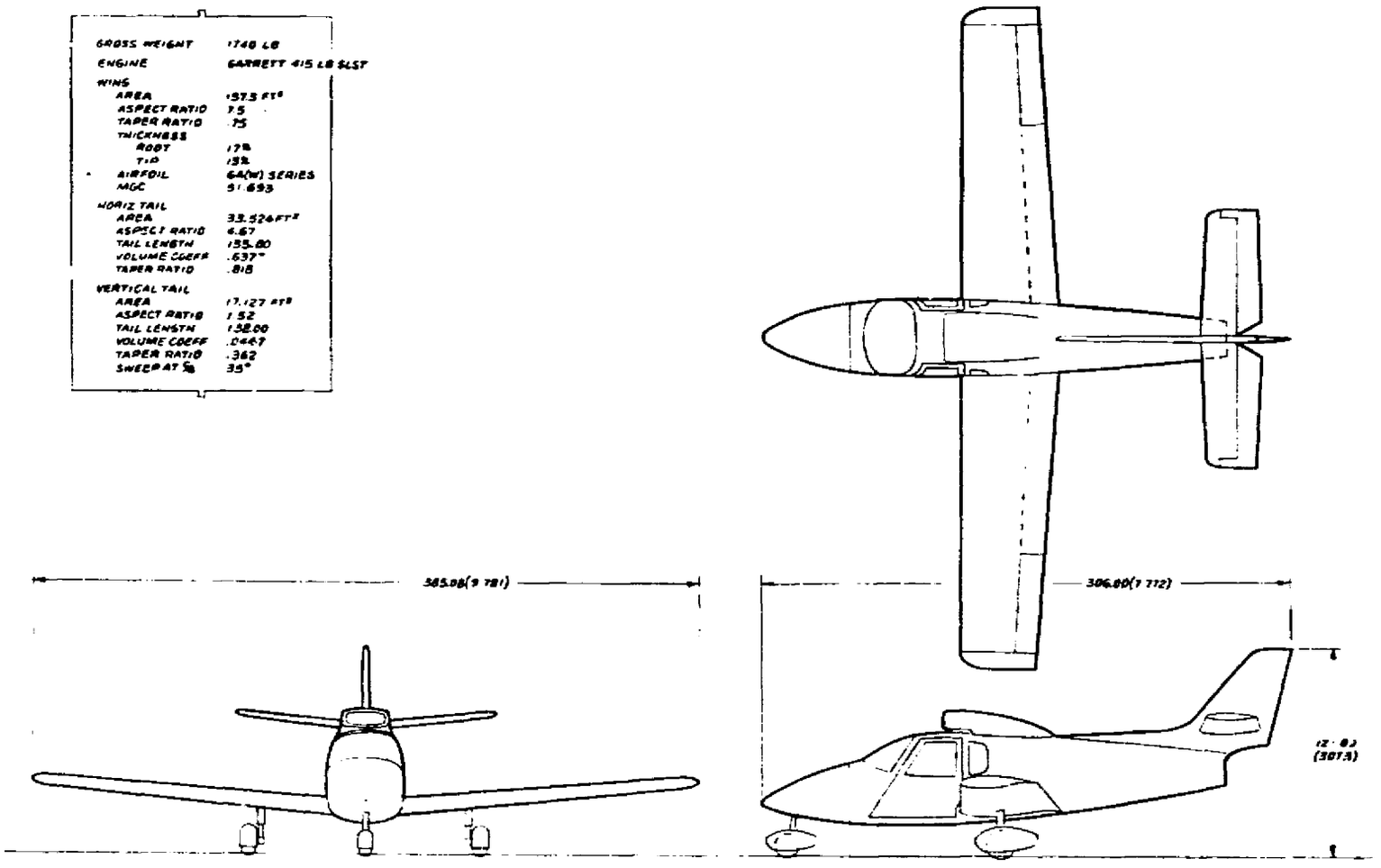


Figure 41
Final Baseline Design
2-Place Trainer

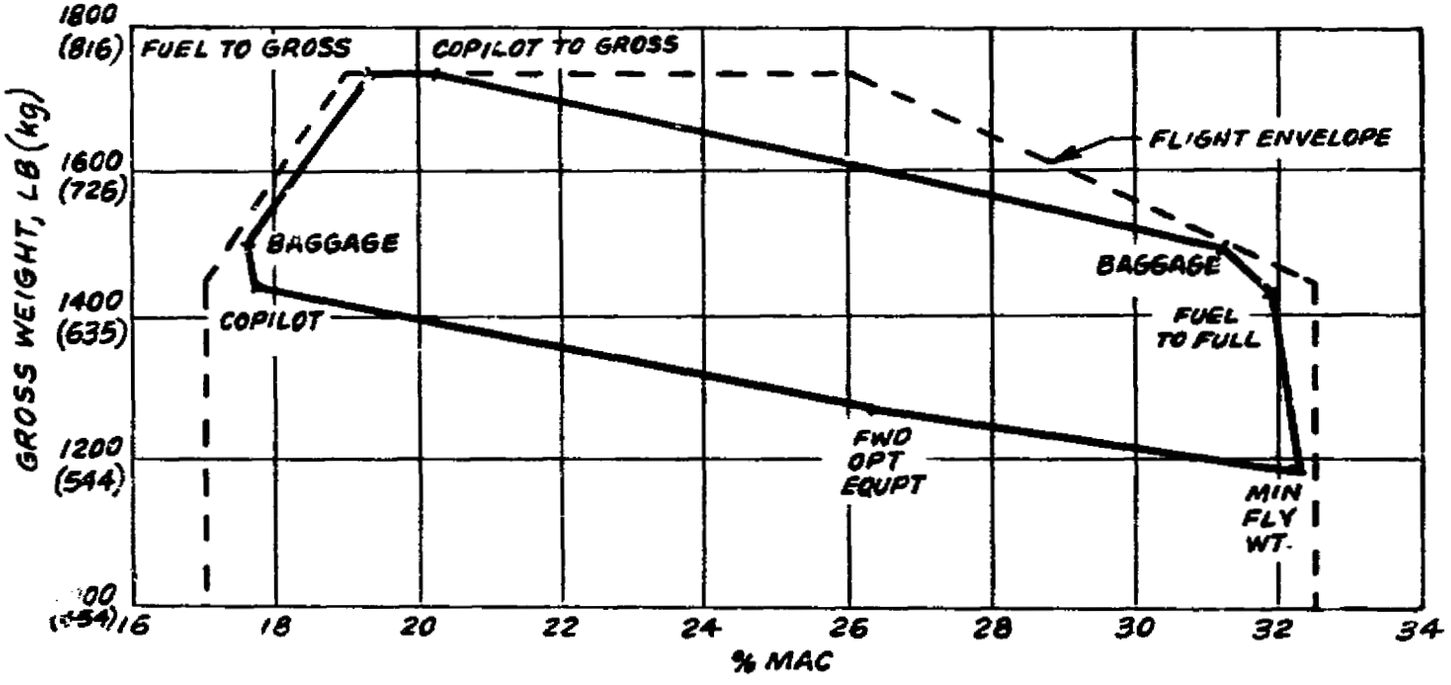


Figure 42. CG Envelope of Final 2-Place Trainer.

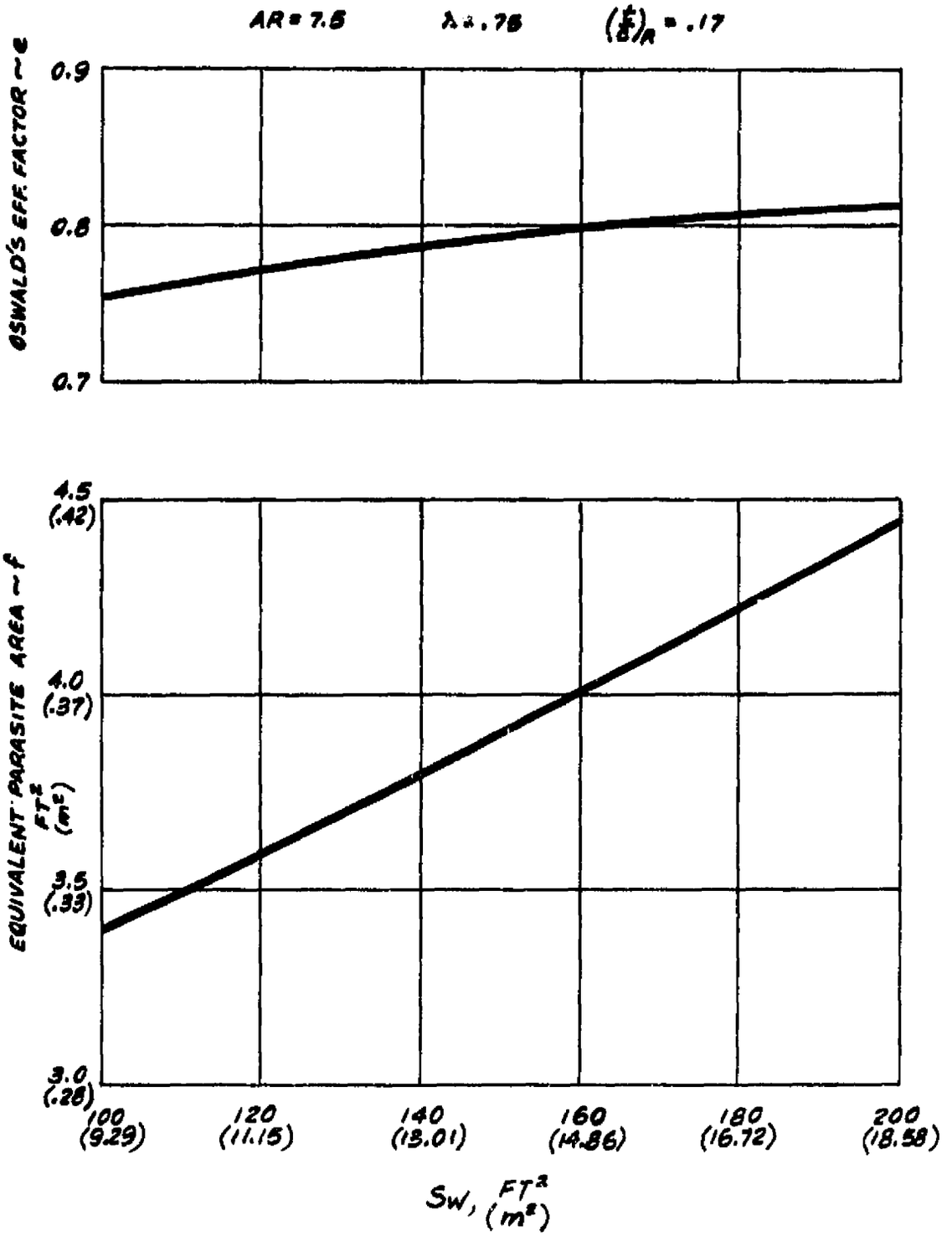


Figure 43. Drag Level for Final Sizing Study. 2-Place Baseline

4.3.2 Engine Optimization by GASP

When generating the inputs into the GASP, certain fundamental decisions were made. Primarily it was decided that the purpose of this study was not to derive a new set of inputs that would duplicate the results of Cessna's methods, but rather to evaluate the GASP as it stands and recommend changes in the basic methodology of the program to bring it into agreement with standard design practices.

In particular, Cessna did not try to make the drag match the results of our methods. Rather the default values of the form factors in subroutine AERO were used.

Since, as was previously explained, it was necessary to expand the thrust maps to accomodate Cessna's analysis, these expanded tables were also incorporated into GASP.

As discussed earlier, in section 4.2.2, GASP is not designed to determine the best cruise speed for maximum range. In order to do this, and thereby match the capability of the GASP sized airplane to the Cessna sized airplane, a matrix of wing loadings and thrusts was established for a series of cruise speeds. The wing loadings were 10, 14, and 20 PSF. The thrust ratings were 400, 500, 600, 700, 800, and 900 lbs. SLST, the matrix being either 3X3 or 3X4 at each speed and the matrix of thrust levels increasing with increasing speed. The range was specified as that which would give endurances of 2.8, 3.5 and 4.2 hours (i.e. desired endurance ± 20%). This was done for MACH numbers of .16, .18, .20 and .23 (102, 115, 128, 147 kts respectively). The results were plotted as "carpet" plots of stall speed, TOFL, DOC and gross weight, vs. wing area and thrust. Examples of each of those, at a cruise speed of 102 kts (M=.16), are shown in Fig. 44, 45, 46 and 47 respectively.

The results of the computer analysis did not yield the wing areas shown. These lines are the results of interpolations between the wing areas that the program generated from the input wing loadings and the resultant gross weights.

From the plot of stall speed, thrust-wing area combinations yielding 50 knots were found and this line plotted onto the gross weight plot. (Fig. 47). Similarly, lines corresponding to a TOFL = 1700 ft and to constant levels of DOC were also added to the gross weight plot.

Nowhere, however, from these graphs is it possible to determine which speed yields the maximum range. It is necessary to know this in order to compare the results of GASP to those of the previous section.

This is found by making, from carpets like these, for each of the 9 combinations of thrust = 500, 600, 700 lb and wing area = 100, 150, 200 ft^2, a new carpet plot of range vs. gross weight and cruise speed. An example of this at 700 lb thrust and 150 sq ft wing area is shown in Fig. 48. The dashed

line is the 3.5 hour endurance line. The dotted line shows the locus of maximum range values for each gross weight. The intersection of these 2 lines is the "complete solution" plane (i.e. 3.5 hr endurance, maximum range) at that thrust and wing area. Each of these "complete solution" planes can then be replotted as a new carpet of gross weight versus thrust and wing area. This new plot, shown in Fig. 49 differs from Fig. 47 in that the speed is varying from point to point. By judicious cross plotting, it was possible to add lines of V_S = 50 kts, TOFL = 1700 ft and lines of constant DOC. The numbers in brackets by the intersection of the lines of the carpet are the cruise speed in knots. As can be seen, the minimum DOC point lies below the 500 lb. thrust line and the cruise speed is below the lowest Mach number actually run (M = .16). Time and money had been exhausted before the lower side of this matrix could be filled in. However, because of the characteristics peculiar to carpet plots it is possible to extrapolate the results with considerable confidence.

The final solution plane is read from the graph as:

W = 1950 lb

S_W = 200 ft^2

DOC = .40 $/nmi (@ depreciation period of 8 years)

Thrust = 435 lb (SLS) (463 lb uninstalled)

Cruise Speed = 91 KTAS

The GASP was used to verify the extrapolation. The verifying run is shown on pages 92 thru 103. Note that the engine price has been adjusted to account for the proper installation losses as discussed in section 4.3.0 and the depreciation period has been modified from 8 years to 7.5 years for consistency with the Cessna method. The DOC, as expected, is higher than the extrapolation would indicate due to these changes in engine cost and depreciation.

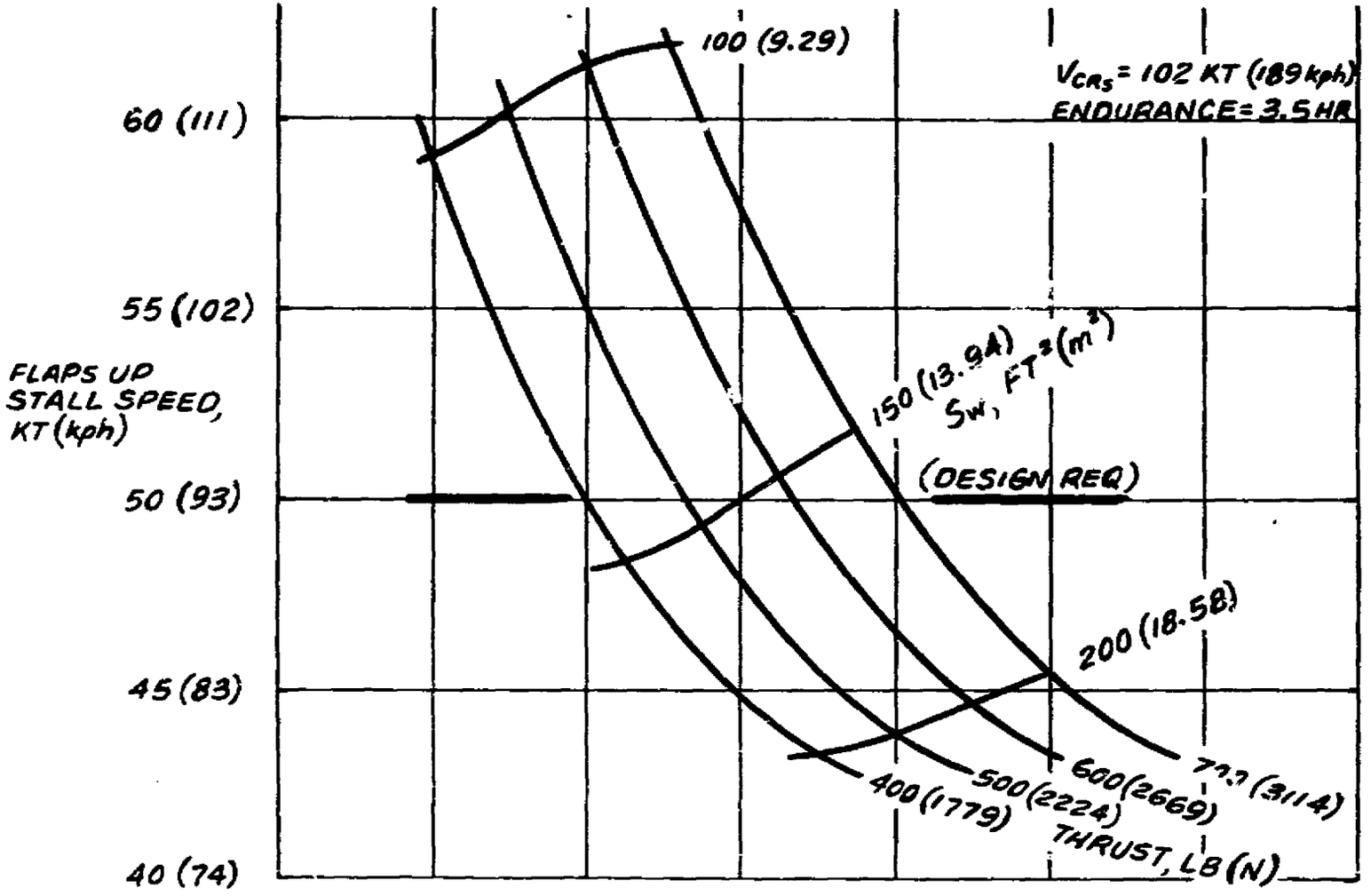


Figure 44. Flaps Up Stall Speed Versus Thrust and Wing Area. Plane Sized for 3.5 hr. Endurance with a Cruise Speed of 102 kts. From the GASP Analysis.

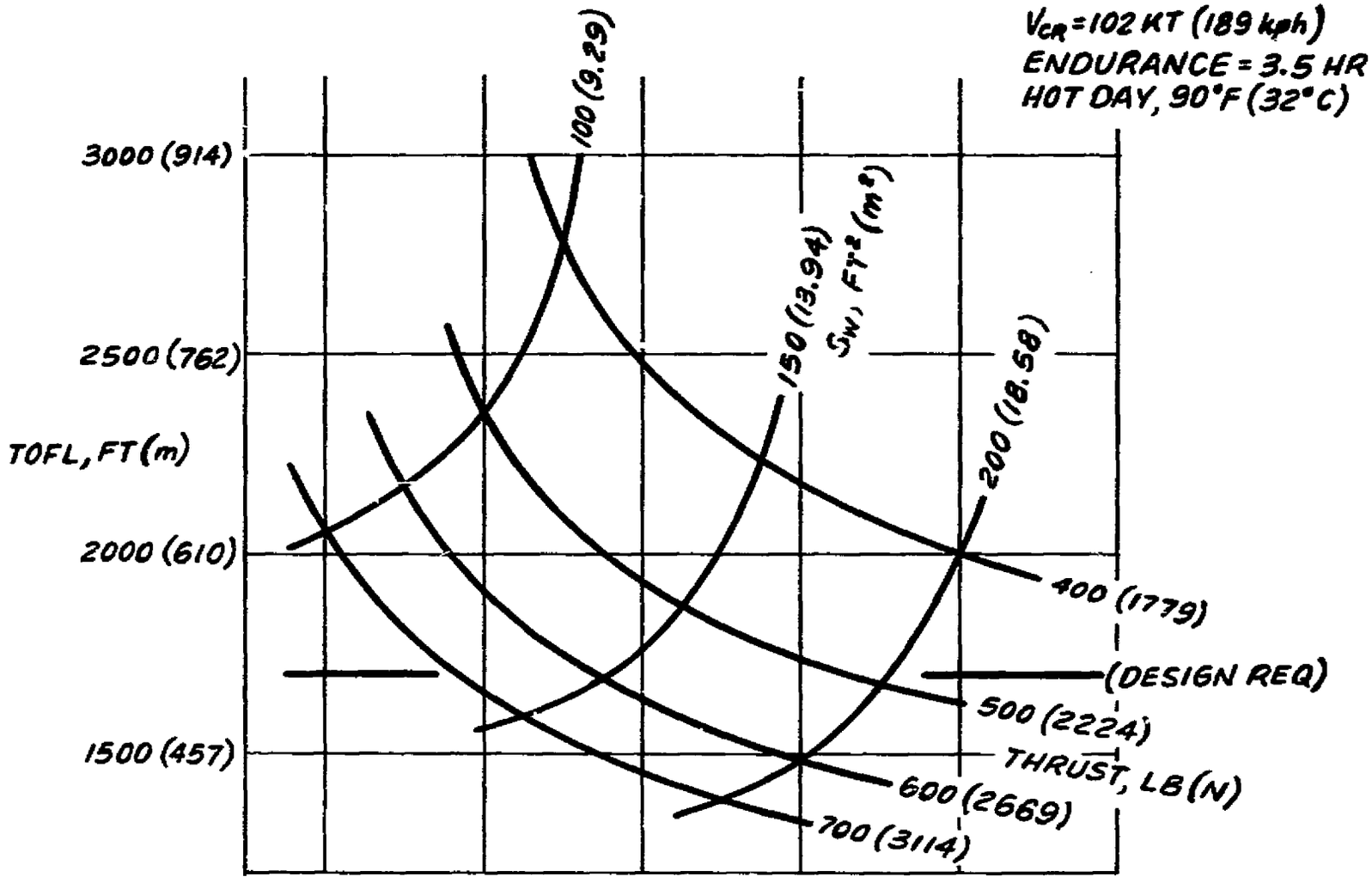


Figure 45. Takeoff Field Length for a 90° Hot Day Versus Thrust and Wing Area. Plane Sized for 3.5 hr Endurance with a Cruise Speed of 102 kts. From the GASP Analysis.

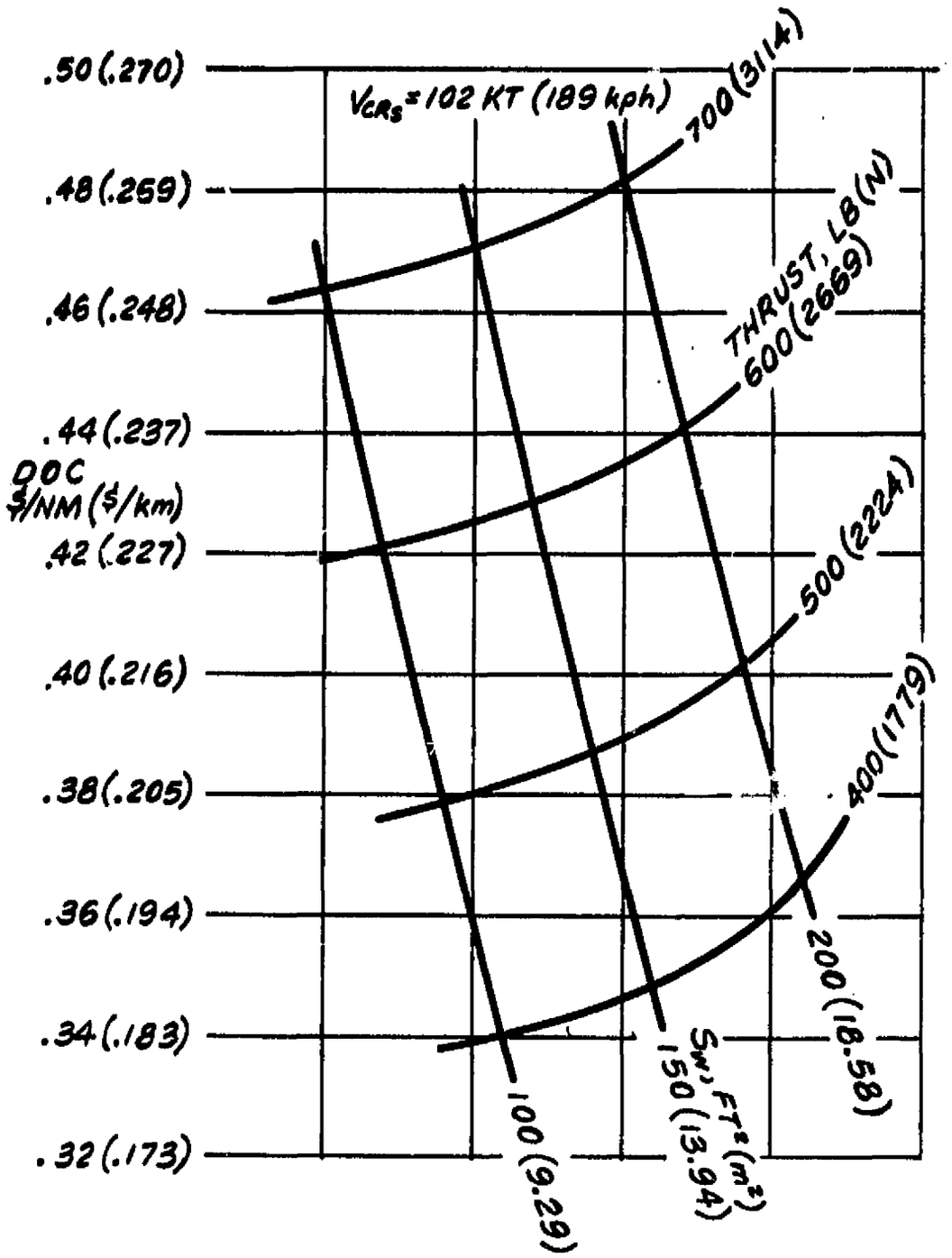


Figure 46. Direct Operating Cost Versus Thrust and Wing Area. Plane Sized for 3.5 hr Endurance with a Cruise Speed of 102 kts. From the GASP Analysis.

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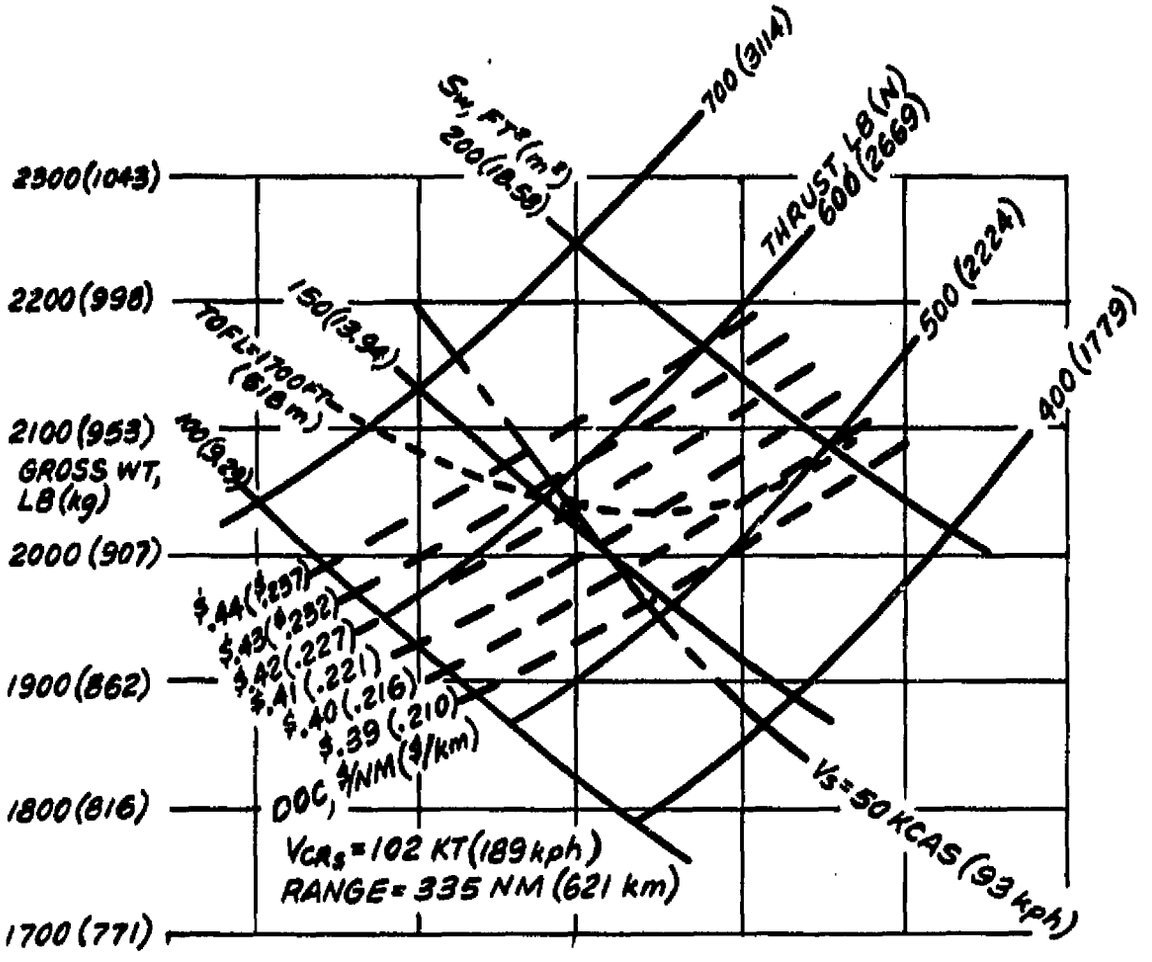

Figure 47. Sizing Plot for the 2-Place Trainer. Cruise Speed = 10.2 knots, Endurance = 3.5 hours. From the GASP Analysis.

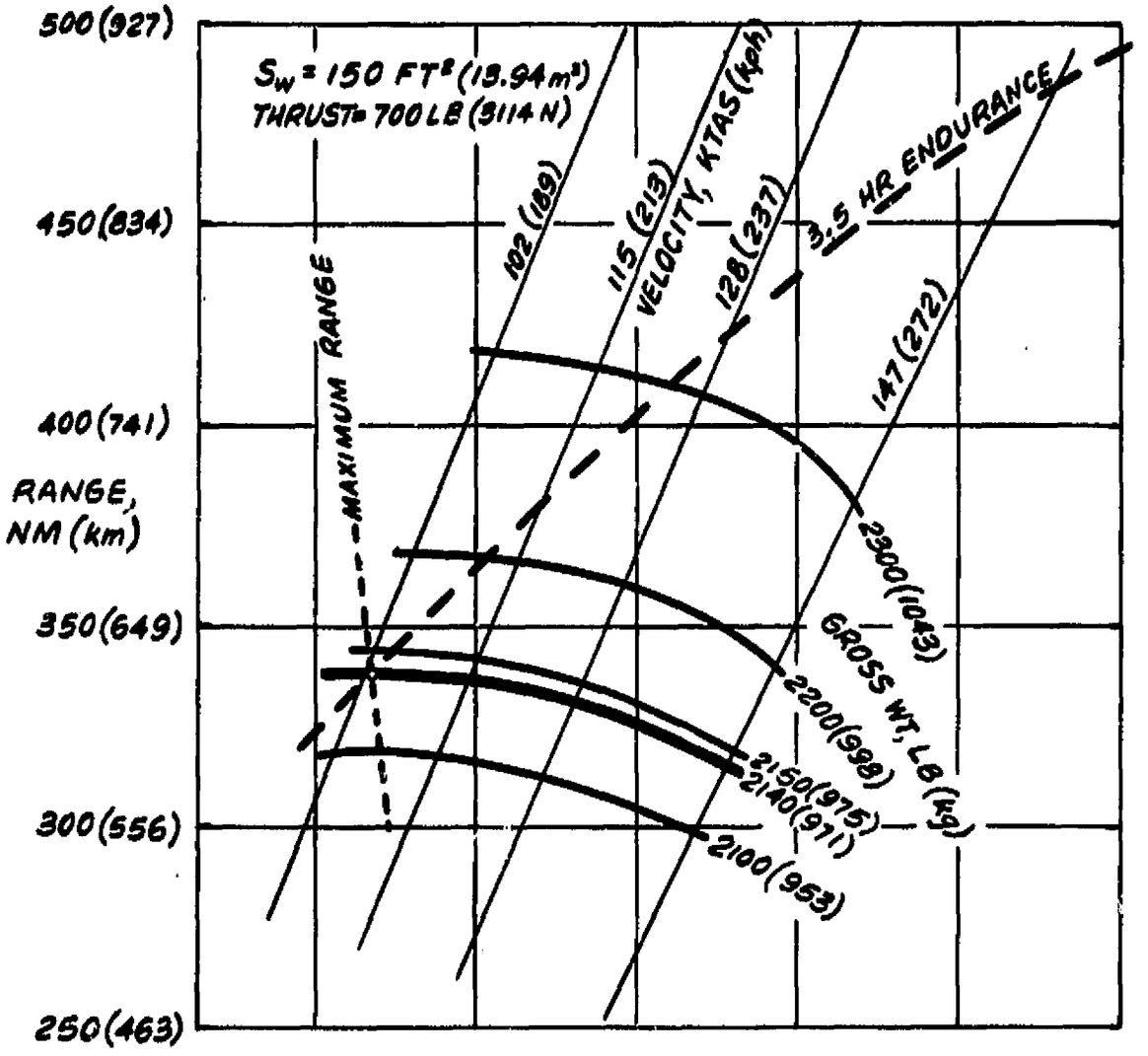

Figure 48. Range at S_W = 150 ft^2, Thrust = 700 lb SLS Versus Gross Weight and Cruise Speed. From the GASP Analysis.

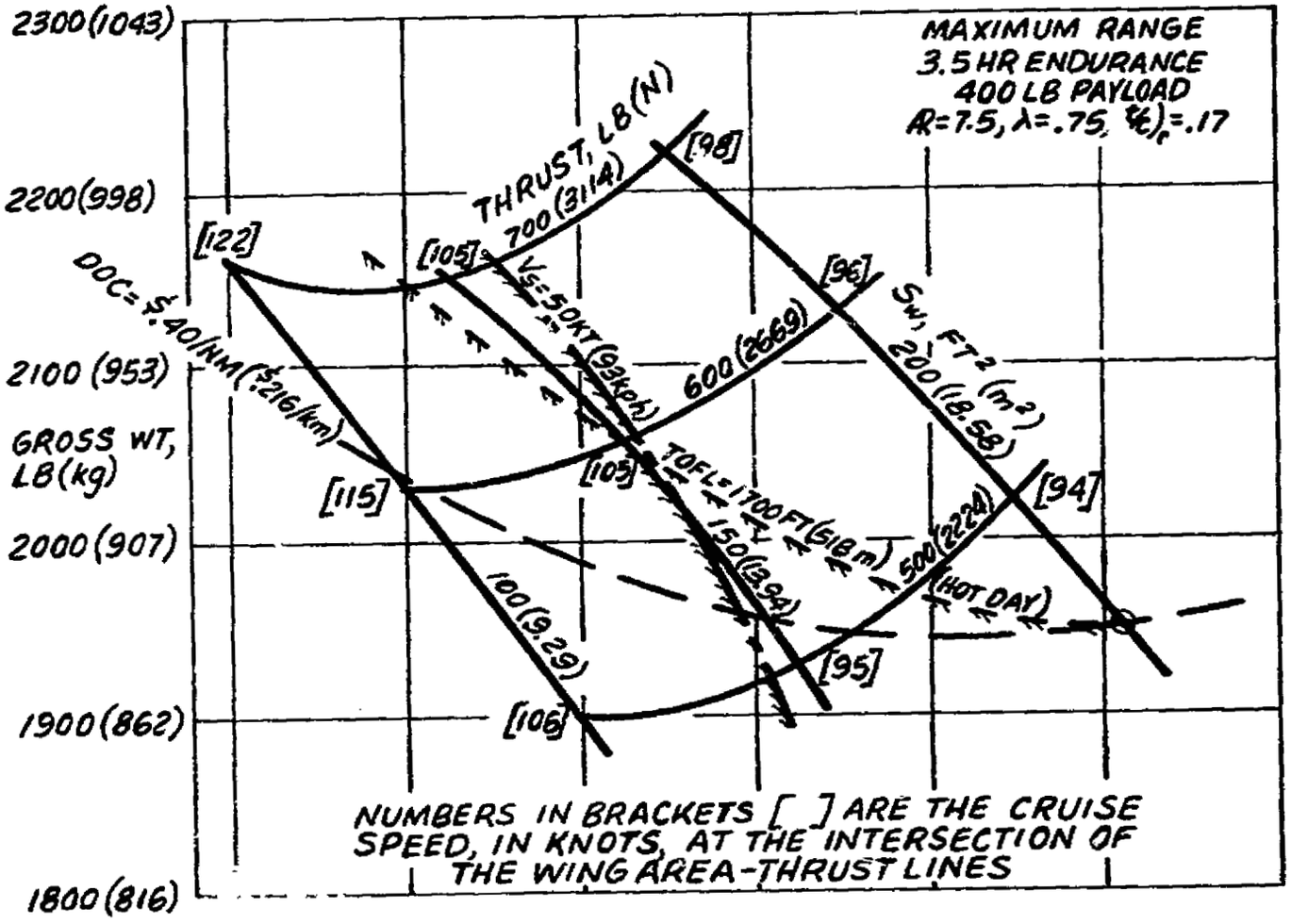

Figure 49. Final Sizing Plot for the 2-Place Trainer. From the GASP Analysis.

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CLIMB-CRUISE THRUST MAPS

```
6
6     9      0.2
             0.0          0.1000      0.2000      0.3000      0.4000      0.5000
2.9000      46.0600      26.1200     13.6300      2.3500     -5.6400    -12.2200
3.2000      81.7800      59.2200     42.7700     28.3880     15.5100      4.7000
3.5000     115.4884      89.1797     70.7491     52.7180     35.7200     21.8916
3.8000     146.2452     116.1652     94.8648     73.9742     54.3640     38.3228
4.1000     172.4900     139.3926    114.6988     91.5363     70.5855     55.5183
4.4000     191.5814     156.2374    129.1278    104.7818     85.6782     76.6796
4.7000     208.7270     171.7662    142.8694    118.3930    101.9618    103.4262
5.0000     226.6622     187.9813    157.4970    133.0100    120.0380    134.8900
5.3000     244.4000     204.9200    172.9600    149.4600    138.1800    170.1400

6     9   3000.0000
             0.0          0.1000      0.2000      0.3000      0.4000      0.5000
2.9000      39.9500      25.3800     13.1600      1.8800     -5.6400    -11.2800
3.2000      72.3800      53.1100     38.5400     24.4400     13.1600      4.7000
3.5000     102.4318      79.0089     62.6209     46.5967     31.4881     19.1807
3.8000     130.0960     103.2214     84.2785     65.6787     48.1524     33.9895
4.1000     153.9814     124.3150    102.3096     81.6155     62.8418     49.2250
4.4000     171.0894     139.6464    115.3474     93.5291     76.3111     68.0325
4.7000     186.3644     153.5114    127.5768    105.8440     90.7720     91.9423
5.0000     202.5418     167.9874    140.6428    118.6186    106.9532    119.7654
5.3000     219.4900     183.7700    153.6900    132.0700    124.0800    152.7500

6     9   6000.0000
             0.0          0.1000      0.2000      0.3000      0.4000      0.5000
2.9000      34.3100      21.6200     11.2800      2.8200     -5.6400    -11.2800
3.2000      63.4500      46.6240     33.4640     22.7480     11.7500      2.8200
3.5000      90.5107      69.7254     55.2090     40.9426     27.6416     16.7273
3.8000     115.3568      91.4723     74.6548     58.0638     42.3312     29.6347
4.1000     137.0332     110.6380     91.0230     72.5680     55.7918     43.5483
4.4000     152.5632     124.4184    102.6856     83.3018     67.8548     60.3396
4.7000     166.1826     136.7042    113.7024     94.1504     80.7404     81.3053
5.0000     180.4612     149.6668    125.2926    105.7124     95.0340    106.1448
5.3000     194.5800     162.6200    137.6160    118.2520    109.9800    133.4800

6     9   9000.0000
             0.2          0.1000      0.2000      0.3000      0.4000      0.5000
2.9000      30.5500      18.0480      9.4000      2.3500     -5.1700     -9.8700
3.2000      55.9300      40.2320     29.1400     19.7400     10.1520      2.3500
3.5000      79.6462      61.2946     48.4636     35.8760     24.1683     14.4910
3.8000     101.9430      80.7779     65.8752     51.2093     37.4317     26.2326
4.1000     121.6078      98.1454     80.7469     64.3355     49.3866     38.3633
4.4000     136.6614     110.4124     91.2289     73.9536     60.0773     53.2134
4.7000     147.7116     121.5044    100.9936     83.6835     71.4738     71.7201
5.0000     160.4956     132.9442    111.3054     93.8223     84.1948     93.8233
5.3000     174.5580     145.2300    122.5760    104.5280     97.7600    117.7820

6    912000.0000
             0.0          0.1000      0.2000      0.3000      0.4000      0.5000
2.9000      26.3200      15.9800      8.9300      1.8800     -5.1700    -10.8100
3.2000      48.4100      34.7800     26.0380     16.9200      8.4600      0.9400
3.5000      69.7565      53.5819     42.3272     31.3631     21.0447     12.4841
3.8000      89.7662      71.0630     57.9256     45.0166     32.8004     22.9089
4.1000     107.5924      86.7892     71.4071     56.8549     43.5596     33.6830
4.4000     120.1414      97.9480     80.9133     65.5255     53.0338     46.7274
4.7000     130.9138     107.6206     89.4429     74.0457     63.1529     62.8653
5.0000     142.2032     117.8760     98.5872     83.0321     74.4508     82.6185
5.3000     154.8180     128.7800    108.5700     92.5900     86.0100    107.3480

6    915000.0000
             0.0          0.1000      0.2000      0.3000      0.4000      0.5000
2.9000      21.6200      12.0320      5.6400      0.9400     -5.1700     -8.1780
3.2000      41.8300      29.6100     21.6200     14.2880      6.5800      1.2220
3.5000      60.8274      46.6099     36.7784     27.1782     18.2087     10.6859
3.8000      78.6893      62.2101     50.7224     39.3663     28.6230     19.9223
4.1000      94.8930      76.5235     62.9499     50.1490     38.3069     29.4568
4.4000     106.2858      86.5185     71.4635     57.8382     46.7941     40.9501
4.7000     115.7704      95.1186     79.0436     65.3995     55.6799     55.0962
5.0000     125.7720     104.1896     87.1079     73.3172     65.4738     72.5999
5.3000     136.5820     114.6800     96.6320     82.2500     75.8580     99.6400
```

CLIMB-CRUISE FUEL FLOW MAPS

```
6
6     9      0.2
             0.0          0.1000      0.2000      0.3000      0.4000      0.5000
2.900       27.3000      26.8000     27.8000     29.3000     31.6000     34.7000
3.200       42.2000      42.4000     43.8000     45.3000     48.7000     52.5000
3.5000      56.3270      56.9340     58.6910     61.1500     64.5150     69.2420
3.8000      70.7150      70.8780     72.8100     75.5080     79.1830     84.4130
4.1000      83.8400      84.5210     86.4860     89.3430     93.3710     99.3970
4.4000      96.3300      97.0620     99.1230    102.3400    107.2300    115.1300
4.7000     108.8900     109.6800    111.9700    115.7000    121.7600    132.6300
5.0000     122.3100     123.1800    125.7100    130.0400    137.5900    152.4000
5.3000     137.8000     139.2000    142.2000    147.2000    157.7000    172.6000
```

```
6     9 3000.0000
            0.0          0.1000          0.2000          0.3000          0.4000          0.5000
2.9000      24.0000      24.4000      25.4000      27.6000      30.3000      34.2000
3.2000      36.8000      37.3000      38.8000      40.3000      43.7000      47.7000
3.5000      49.5180      50.0590      51.6200      53.8030      56.7870      60.9730
3.8000      61.7990      62.3780      64.1010      66.4890      69.7380      74.3570
4.1000      73.6920      74.5040      76.2390      78.7620      82.3110      87.6060
4.4000      84.9360      85.5810      87.4020      90.2310      94.5320      101.4500
4.7000      95.9900      96.6990      98.7030      102.0000     107.3000     116.8120
5.0000      107.7900     108.5600     110.7800     114.5900     121.2200     134.1700
5.3000      121.7000     121.7000     124.7000     128.8000     138.6000     157.0000

6     9 6000.0000
            0.0          0.1000          0.2000          0.3000          0.4000          0.5000
2.9000      20.5000      20.9000      22.3000      24.0000      26.0000      28.6000
3.2000      32.2000      32.5000      34.2000      35.7000      38.0000      41.3000
3.5000      43.2960      43.8770      45.2620      47.1880      49.8400      53.5470
3.8000      54.2370      54.7550      56.2750      58.3840      61.2500      65.3270
4.1000      64.9600      65.4890      67.0280      69.2500      72.3710      77.0060
4.4000      74.6940      75.2640      76.8640      79.3520      83.1190      89.1730
4.7000      84.4060      85.0250      86.7940      89.6800      94.3280      102.6000
5.0000      94.7410      95.4180      97.3800      100.7200     106.5200     117.8300
5.3000      105.6000     106.6000     108.7000     112.4000     120.2000     136.4000

6     9 9000.0000
            0.0          0.1000          0.2000          0.3000          0.4000          0.5000
2.9000      18.3000      18.3000      19.6000      20.7000      22.5000      25.2000
3.2000      28.1000      28.4000      29.7000      31.1000      33.2000      36.1000
3.5000      37.8990      38.3460      39.5550      41.2680      43.6100      46.8740
3.8000      47.4490      47.9110      49.2380      51.1140      53.6390      57.2450
4.1000      56.9420      57.4080      58.7640      60.7190      63.4550      67.5060
4.4000      65.5120      66.0120      67.4210      69.5960      72.8830      78.1610
4.7000      74.2190      74.7620      76.1120      78.6400      82.6920      89.8870
5.0000      83.0560      83.6450      85.3630      88.2870      93.3410      103.2000
5.3000      93.2000      93.9000      96.3000      100.3000     106.2000     120.3000

6     912000.0000
            0.0          0.1000          0.20         0.3000          0.4000          0.5000
2.9000      16.1000      16.6000      17.1000      18.2000      20.4000      23.2000
3.2000      24.5000      25.0000      25.8000      27.3000      29.3000      32.0000
3.5000      32.9740      33.3630      34.4460      35.9600      38.0320      40.9110
3.8000      41.3800      41.7720      42.9660      44.6050      46.8260      49.9910
4.1000      49.7610      50.1730      51.3670      53.0830      55.4770      59.0090
4.4000      57.2950      57.7320      58.9690      60.8700      63.7310      68.3040
4.7000      64.7270      65.2030      66.5550      68.7620      72.2690      78.5030
5.0000      72.6010      73.1160      74.6180      77.1710      81.5720      90.1130
5.3000      81.2000      81.6000      83.0000      86.3000      91.2000      104.2000

6     915000.0000
            0.0          0.1000          0.2000          0.3000          0.4000          0.5000
2.9000      13.4000      13.8000      14.7000      16.0000      17.8000      19.7000
3.2000      21.2000      21.3000      22.3000      23.6000      25.4000      27.6000
3.5000      28.5990      28.9220      29.8810      31.2220      33.0510      35.5750
3.8000      35.9420      36.3120      37.3560      38.7940      40.7420      43.5120
4.1000      43.3540      43.7160      44.7620      46.2660      48.3540      51.4280
4.4000      49.9620      50.3440      51.4210      53.0830      55.5650      59.5220
4.7000      56.4390      56.8530      58.0330      59.9510      63.0110      68.3720
5.0000      63.2780      63.7270      65.0350      67.2550      71.0580      78.4620
5.3000      71.5000      71.5000      72.6000      75.1000      79.5000      90.7000
   CLIMB-CRUISE AIRFLOW MAPS
6

6     9    0.0
            0.0          0.1000          0.2000          0.3000          0.4000          0.5000
2.9000      7.2000       7.6000       8.4600       9.3600       10.6500      12.1600
3.2000      8.9800       9.2800       10.0500      10.8100      11.7800      12.9300
3.5000      10.5430      10.7830      11.4260      12.0960      12.8290      13.6770
3.8000      11.8230      12.0220      12.5800      13.1200      13.8830      14.3620
4.1000      12.7900      12.9580      13.4000      13.8480      14.3350      14.9990
4.4000      13.4200      13.5630      13.9230      14.3290      14.8830      15.7670
4.7000      13.9520      14.0790      14.3910      14.8000      15.4450      16.6710
5.0000      14.4860      14.5880      14.8660      15.2690      16.0340      17.6570
5.3000      14.9700      15.0800      15.3400      15.7400      16.6500      18.7500

6     9 3000.0000
            0.0          0.1000          0.2000          0.3000          0.4000          0.5000
2.9000      7.1800       7.5800       8.4000       9.3400       10.6400      12.1200
3.2000      8.9400       9.2400       10.0080      10.7800      11.7500      12.9100
3.5000      10.4890      10.7320      11.3800      12.0570      12.7990      13.6550
3.8000      11.7790      11.9820      12.5420      13.0880      13.6560      14.3410
4.1000      12.7630      12.9350      13.3790      13.8290      14.3170      14.9830
4.4000      13.4010      13.5440      13.9080      14.3160      14.8660      15.7390
4.7000      13.9330      14.0610      14.3740      14.7870      15.4190      16.6410
5.0000      14.4660      14.5730      14.8480      15.2490      16.0110      17.6190
5.3000      14.9700      15.0700      15.3200      15.7200      16.6400      18.7000
```

```
 6     9 6000.0000
             0.0          0.1000       0.2000       0.3000       0.4000       0.5000
 2.9000      7.1500       7.3500       8.3400       9.5200      10.6300      12.0900
 3.2003      8.8903       9.2000       9.9600      10.7500      11.7200      12.8900
 3.5000     10.4280      10.6730      11.3270      12.0130      12.7660      13.6310
 3.8000     11.7300      11.9340      12.5030      13.0530      13.6270      14.3180
 4.1002     12.7370      12.9060      13.3970      13.8040      14.2980      14.9660
 4.4000     13.3830      13.5260      13.8910      14.3000      14.8470      15.7140
 4.7000     13.9142      14.0390      14.3580      14.7690      15.4040      16.6050
 5.0003     14.4440      14.5530      14.8310      15.2340      15.9880      17.5850
 5.3000     14.9600      15.0600      15.3000      15.7000      16.6300      18.6500

 6     9 9000.0000
             0.0          0.1000       0.2000       0.3000       0.4000       0.5000
 2.9000      7.1100       7.4500       8.2500       9.3000      10.6200      12.0620
 3.2000      8.8300       9.1700       9.9200      10.7200      11.6900      12.8500
 3.5003     10.3670      10.6120      11.2680      11.9650      12.7310      13.6060
 3.8000     11.6750      11.8840      12.4520      13.0140      13.5960      14.2950
 4.1002     12.7060      12.8770      13.3320      13.7880      14.2780      14.9280
 4.4003     13.3620      13.5020      13.8740      14.2860      14.8240      15.6840
 4.7000     13.8930      14.0190      14.3400      14.7920      15.3770      16.5680
 5.0003     14.4220      14.5250      14.8100      15.2150      15.9600      17.5520
 5.3000     14.9600      15.0500      15.2800      15.6800      16.6100      18.6200

 6     91200.0000
             0.0          0.1000       0.2000       0.3000       0.4000       0.5000
 2.9000      7.0500       7.3500       8.1500       9.2000      10.5700      11.9200
 3.2003      8.6800       9.0200       9.7500      10.6300      11.6800      12.7900
 3.5000     10.2760      10.5320      11.2000      11.9080      12.6920      13.5740
 3.8000     11.6180      11.8260      12.4060      12.9720      13.5610      14.2670
 4.1000     12.6700      12.8450      13.3050      13.7640      14.2560      14.9020
 4.4000     13.3392      13.4840      13.8570      14.2670      14.8040      15.6500
 4.7003     13.8692      13.9970      14.3190      14.7340      15.3540      16.5210
 5.0000     14.3970      14.5080      14.7890      15.1900      15.9400      17.5100
 5.3003     14.8900      15.0200      15.2500      15.6500      16.5400      18.6000

 6     915000.0000
             0.0          0.1000       0.2000       0.3000       0.4000       0.5000
 2.9000      7.0000       7.2500       7.9600       9.0200      10.5000      11.9000
 3.2000      8.6200       9.9200       9.6400      10.5300      11.6300      12.7300
 3.5002     10.1910      10.4460      11.1230      11.8480      12.6500      13.5430
 3.8000     11.5440      11.7610      12.3510      12.9220      13.5210      14.2330
 4.1002     12.6362      12.8110      13.2750      13.7410      14.2300      14.8760
 4.4000     13.3200      13.4630      13.8370      14.2460      14.7840      15.6170
 4.7002     13.8470      13.9760      14.3000      14.7120      15.3310      16.4790
 5.0002     14.3780      14.4860      14.7690      15.1730      15.9020      17.4720
 5.3000     14.8800      14.9800      15.2200      15.6200      16.4900      18.5000

*****START OF INPUT FOR CONTROL
      / SMALL TURBOFAN STUDY - 2 PLACE UTILITY AIRCRAFT - CESSNA L
       NPC=1,NSC=1,IDC=0,NTYE=7,EMCRU=.18,HNCRU=10000.,EM=.18,
       ALT=10000.,ENP=1.,WG=1700.,KWRITE=2,
       EM=.142,
       EMCRU=.142,
       WG=1950.,
       WGS=9.75,
       *

*****START OF INPUT FOR VEHICLE SIZING
       SAB=2.,WS=20.,AS=0.,WAS=0.,PAX=1.,PS=0.,DELP=0.,WPLX=200.,WFEX=135.2,
       AR=7.5,TCR=.17,TCT=.13,SLM=.75,
       KCONFG=0,DLNC4=0.,YP=0.,YMG=.333,EYEW=1.0,ALPHLO=-4.0,IGEAR=1,
       CATD=0.,SAH=.2,ARHT=4.667,ARVT=1.52,TCHT=.09,TCVT=.10,SLMH=.818,
       SLMV=.362,KTIPX=0,VMLFSL=200.,KNAC=2,ELRW=0.,ELN=5.,DBARN=.85,
       CDELTH=.37258,RDELTV=2.71729,
       WENG=201.0,WNAC=27.6,WPYLON=0.,WPROP1=0.,WFUL=200.,
       WFNG=124.9,
       ELODN=1.5676,HCK=1.25,ELPC=4.75,ELODT=2.9423,*

*****START OF INPUT FOR CONTROL
       NPC=2,NSC=1,IDC=0,*

*****START OF INPUT FOR CONTROL
       NPC=1,NSC=7,*

*****START OF INPUT FOR CRUISE AERODYNAMICS
       DELEF=0.,
       CKTP=0.,KWCD=0,*

*****START OF INPUT FOR CONTROL
       NPC=2,NSC=2,IDC=0,*
```

```
SUMMARY OF CRUISE LIFT-WEIGHT BALANCE
  ANGLE OF ATTACK(DEGREES)      1.990 LIFT     1950.0 L/D     11.902 ALTITUDE   10000.0

*****START OF INPUT FOR CONTROL
      NPC=1,NSC=14,IDC=1,*

*****START OF INPUT FOR FLAP PARAMETERS
      VKTIN=60.,DFLFD=0.,CLFNC=0.,DELLED=0.,PCLMAX=1.63,
      IFLAP=1,*
    DCLMTE,DELTED,DCDMTE,WCFLAP =   1.1800  40.0000   0.1300   0.7330

*****START OF INPUT FOR CONTROL
      NPC=2,NSC=14,IDC=0,*

TAKEOFF  DFLCL=  0.0     DELCD=  0.0     CLMAX=  1.5702  DELTA6=  1.0000  SIGMTO = 0.0

*****START OF INPUT FOR CONTROL
      NPC=1,NSC=14,IDC=0,*

*****START OF INPUT FOR FLAP PARAMETERS
      VKTIN=65.,DFLFD=0.,CLFNC=0.,DELLED=0.,PCLMAX=1.63,
      DCLMTE=1.04,DELTED=30.,RTFDB=.50,
      IFLAP=2,*
    DCLMTE,DELTED,DCDMTF,WCFLAP =   1.0800  30.0000   0.1300   0.7330

*****START OF INPUT FOR CONTROL
      NPC=2,NSC=14,IDC=0,*

LANDING  DFLCL=  0.0     DELCD=  0.0     CLMAX=  1.5813  DELTA6=  1.0000  SIGMLD = 0.0

*****START OF INPUT FOR CONTROL
      NPC=1,NSC=12,IDC=0,*

*****START OF INPUT FOR LANDING MANUVER
      IWLD=1,
      WSMX=670.,*

*****START OF INPUT FOR CONTROL
      NPC=2,NSC=12,*

 ************************************************************************************************************

          TEMP.=  518. DEG STD.+ 0.
   LANDING ELEVATION=    0. FT.
   LANDING WING LOADING=   9.75 PSF.
   LANDING WEIGHT =     1950. LBS.

   LANDING DISTANCE FROM 50. FT.=   1091. FT.

   F.A.R. FACTORED FIELD LENGTH =   1819. FT.

                    APPROACH            TRANSITION            DELAY                 ROLL

                DIST=       637.    DIST=       18.    DIST=       63.    DIST=       353.
                B/S=        491.    XLFMX=    1.200    TDELAY=   1.00    MUB=      0.3500
                VAPEAS=   55.26     SINKTD=   3.000    TIDLE=     0.     TR/TIDLE=  0.0
                VAPTAS=   59.52     VSTEAS=   42.53                      ABAR(G)=   0.3006
                THETA=     4.49     CLMX=     1.5802
                THRUST=       0.
 IDLE THRUST LIMITING RATE OF SINK
 ************************************************************************************************************

*****START OF INPUT FOR CONTROL
      NPC=1,NSC=6,IDC=0,*

*****START OF INPUT FOR MISSION DESCRIPTION
      ICOND=1,ISEG=9,*

*****START OF INPUT FOR CONTROL
      NPC=1,NSC=10,IDC=0,
      EM=.142,ALT=10000.,KWRITE=2,*

*****START OF INPUT FOR PROPULSION SIZING
      IDART=3,THIN=700.,JENGSZ=4,RCCRU=100.,
      THIN=435.1
      HRTP=.35,*

*****START OF INPUT FOR CONTROL
      NPC=2,NSC=10,IDC=0,*
```

```
TAKE OFF RATE OF CLIMB REQUIREMENTS - FAR PART 23
   AIRPORT ALTITUDE=       0. FT     AMBIENT TEMP ABOVE STD. DAY=      0.0 DEG F

  CONFIGURATION                                ALT (FT)     V (KTAS)   R/C (FPM)   R/C REQ (FPM)    CL REQ       L/D

  T.O. FLAPS - ALL ENGINES                          0.         55.7       624.23         492.69         0.93        12.76
  LANDING FLAPS+LD GEAR EXT - ALL ENGINES           0.         55.5       620.43         245.48         0.94        12.74

ENGINE SIZE SPECIFIED BY INPUT - SLS AIRFLOW=     31.23
RATED SEA LEVEL STATIC THRUST PER ENGINE=     435.0 LBS (UNINSTALLED THRUST= 435/.94 = 465 LB)
**********************************************************************************************************************

+++++START OF INPUT FOR CONTROL
      NPC=1,NSC=13,IDC=0,*

+++++START OF INPUT FOR PROPULSION WEIGHT
      SWSLS=.28713,*

+++++START OF INPUT FOR CONTROL
      NPC=2,NSC=13,IDC=0,*
XXXXX--KNAC IS INPUT AS 2 IN SIZE WHICH FIXES NACELLE DIMENSIONS THEY SHOULD HAVE BEEN INPUT IN SIZE AS ELH & DCARN-

+++++START OF INPUT FOR CONTROL
      NPC=1,NSC=4,IDC=0,*

+++++START OF INPUT FOR VEHICLE WEIGHT OR WING LOC.
      SKPEI=.1603,SKLG=.0657,SKWG=.7022,SKPES=0.,SKV=.204,SKZ=.227,
      SKWW=160.,SKWF=.4029,EGMRGN=1.4014,
      SKR=113.,SKCC=11.5,SKFW=.485,SKFS=.119,FUELD=6.7,LCWING=0,
      RFLP=.679,CPMRGN=.25,RELP=.42,UMPAX=170.,
      DWPQCH=0.,ELINC=1.25,*

+++++START OF INPUT FOR CONTROL
      NPC=2,NSC=4,IDC=0,*

+++++START OF INPUT FOR CONTROL
      NPC=2,NSC=5,IDC=0,*
```

GROSS WEIGHT = 1950. PASSENGERS = 1. PLUS CREW OF 1

FUSELAGE	LENGTH	(ELF)	22.33	FT
	WIDTH	(SWF)	4.33	FT
	WETTED AREA	(SF)	220.	SQFT
	DELTA P	(DELP)	0.0	PSI
WING	ASPECT RATIO	(AR)	7.50	
	AREA	(SW)	200.0	SQFT
	SPAN	(B)	38.7	FT
	GEOM. MEAN CHORD	(CBARW)	5.20	FT
	QUARTER CHORD SWEEP	(DLMC4)	0.0	DEG
	TAPER RATIO	(SLM)	0.750	
	ROOT THICKNESS	(TCR)	0.170	
	TIP THICKNESS	(TCT)	0.130	
	WING LOADING	(WGS)	9.8	PSF
	WING FUEL VOLUME	(VFW)	45.3	CUFT
HOR. TAIL	ASPECT RATIO	(ARHT)	4.67	
	AREA	(SHT)	51.9	SQFT
	SPAN	(BHT)	15.57	FT
	MEAN CHORD	(CBARHT)	3.35	FT
	THICKNESS/CHORD	(TCHT)	0.090	
	MOMENT ARM	(ELTH)	14.0	FT
	VOLUME COEFF.	(VBARH)	0.697	
VERT. TAIL	ASPECT RATIO	(ARVT)	1.52	
	AREA	(SVT)	43.2	SQFT
	SPAN	(BVT)	8.10	FT
	MEAN CHORD	(CBARVT)	5.72	FT
	THICKNESS/CHORD	(TCVT)	0.100	
	MOMENT ARM	(ELTV)	14.3	FT
	VOLUME COEFF.	(VBARV)	0.080	
ENG.NACELLES	LENGTH	(ELN)	5.00	FT
	MEAN DIAMETER	(DBARN)	0.85	FT
	NUMBER ENGINES	(ENP)	1.0	
	WETTED AREA	(SN)	13.35	SQFT

VDIVE = 174. KTS VMO = 148. KTS MMO = 0.445
ULT. LF = 5.97 MAN. LF = 3.80 GUST LF = 3.98

PROPULSION GROUP			
PRIMARY ENGINES	(WEP)	125.	
PRIMARY ENGINE INSTL.	(WPEI)	20.	
FUEL SYSTEM	(WFSS)	45.	
PROPULSOR WEIGHT	(WPROP)	0.	
TOTAL PROP.GROUP WT.	(WP)	190.	
STRUCTURES GROUP			
WING	(WW)	315.	
HOR. TAIL	(WHT)	70.	
VERT. TAIL	(WVT)	36.	
FUSELAGE	(WB)	224.	
LANDING GEAR	(WLG)	128.	
PRIMARY ENG. SECTION	(WPES)	28.	
GROUP WEIGHT INC.	(DELWST)	0.	
TOTAL STRUC.GROUP WT.	(WST)	800.	
FLIGHT CONTROLS GROP			
COCPIT CONTROLS	(WC[illegible])	15.	
FIXED WING CONTROLS	(WCFW)	34.	
SAS	(WSAS)	0.	
GROUP WEIGHT INC.	(DELW[illegible])	0.	
TOTAL CONTROL WT.	(WFC)	49.	
WT. OF FIXED EQUIPMENT	(WFE)	35[illegible].	
WEIGHT EMPTY	(WE)	1[illegible]74.	
FIXED USEFUL LOAD	(WFUL)	200.	(INC. CREW OF 1)
OPERATING WEIGHT EMPTY	(OWE)	1374.	
PAYLOAD	(WPL)	200.	(PAX= 1.)
FUEL	(WFA)	376.	(WFW= 376.) (WFTP= 0.)
GROSS WEIGHT	(WG)	1950.	

CRUISE MACH = 0.142 CRUISE ALTITUDE = 10000.

CRUISE RE.NUM. PER FT. = 7.6120 05 FLATPLATE CF AT RE=10EX7 IS 0.00292

AERODYNAMIC DATA

DRAG BREAKDOWN	FLATPLATE AREA(SQFT)	CDO	WETTED AREA(SQFT)
WING	1.9100	0.00955	374.61
FUSELAGE	1.1561	0.00578	219.85
VERT.TAIL	0.3510	0.00176	86.42
HOR. TAIL	0.4899	0.00245	103.85
ENGINE NAC.	0.0719	0.00036	13.35
TIP TANKS	0.0	0.0	0.0
INCREMENTAL	0.3000	0.00150	0.0
FIXED GEAR	1.3714	0.00686	NOT INCL.
TOTAL	5.6504	0.02825	798.08

MEAN SKIN FRICTION COEF.= 0.007080

AERODYNAMIC COEFF.

A1		0.7122	
A2		-0.1157	
A3		0.0625	
A4=.75X(T/C)		0.1125	
A5=CDO--		0.0187	
A6		3.2722	
A7=1/(PI.SEE.AR)		0.0515	
3-D LIFT SLOPE AT CRUISE MACH	(CLALPH)	4.8638	PER RADIAN
OSWALD FACTOR	(SFE)	0.8226	

CRUISE CD = 0.0283 + 0.0516 CL2

+++++START OF INPUT FOR CONTROL
NPC=2,NSC=6,IDC=0,*

+++++START OF INPUT FOR MISSION DESCRIPTION
ICONO=0,ISEG=1,DELTT=.2,*

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

MISSION PERFORMANCE DATA FOLLOWS

TAXI AT IDLE THRUST

TIME (HRS)	RANGE (NM)	FUEL USED (LBS)	WEIGHT (LBS)	ALT. (FT)	FUEL FLOW (LB/HR)
0.0	0.	0.	1950.	0.	0.
0.200	3.	19.	1932.	0.	0.

*****START OF INPUT FOR MISSION DESCRIPTION
TOFLTX=31.,
TSEG=2,HTG=2.5,*

VSTLKT= 69.5 KTS EAS VRAT= 1.235 CLTO= 1.0341
VEND = 72.1 KNOTS EAS

(TEMP.= 550. DEG STD.+21.)

TAKEOFF ELEVATION= 0. FT

TIME (SEC)	DIST. (FEET)	FUEL USED (LBS)	WEIGHT (LBS)	ALT. (FT)	TAS (KTS)	EAS (KTS)	MACH NO.	ACCEL (FPS2)	CL	CD	ALPHA (DEG)	GAMMA (DEG)	ROC (FPM)	LOAD FACT	THRUST (LBS)	FUEL FLOW (LB/HP)	FUS. ANGLE (DEG)
0.0	0.0	18.0	1932.	0.0	0.0	0.0	0.0	5.99	0.4669	0.0333	1.00	0.0	0.0	0.0	398.	193.	0.0
1.0	3.0	18.0	1932.	0.0	3.5	3.4	0.005	5.91	0.4669	0.0333	1.00	0.0	0.0	0.0	394.	193.	0.0
2.0	11.9	18.1	1932.	0.0	7.0	6.8	0.010	5.83	0.4669	0.0333	1.00	0.0	0.0	0.0	389.	193.	0.0
3.0	26.7	18.1	1932.	0.0	10.5	10.2	0.015	5.74	0.4669	0.0333	1.00	0.0	0.0	0.0	385.	193.	0.0
4.0	47.2	18.2	1932.	0.0	13.8	13.4	0.020	5.65	0.4669	0.0333	1.00	0.0	0.0	0.0	381.	193.	0.0
5.0	73.4	18.3	1932.	0.0	17.2	16.7	0.025	5.56	0.4650	0.0333	1.00	0.0	0.0	0.0	377.	193.	0.0
6.0	105.1	18.3	1932.	0.0	20.4	19.9	0.030	5.46	0.4650	0.0333	1.00	0.0	0.0	0.0	373.	193.	0.0
7.0	142.3	18.4	1932.	0.0	23.6	23.0	0.035	5.36	0.4650	0.0333	1.00	0.0	0.0	0.0	369.	193.	0.0
8.0	185.0	18.4	1932.	0.0	26.8	26.0	0.039	5.25	0.4651	0.0333	1.00	0.0	0.0	0.0	365.	193.	0.0
9.0	232.8	18.5	1932.	0.0	29.9	29.0	0.044	5.15	0.4652	0.0333	1.00	0.0	0.0	0.0	362.	193.	0.0
10.0	285.9	18.5	1931.	0.0	32.9	32.0	0.048	5.04	0.4652	0.0333	1.00	0.0	0.0	0.0	358.	193.	0.0
11.0	344.0	18.6	1931.	0.0	35.9	34.9	0.053	4.93	0.4653	0.0333	1.00	0.0	0.0	0.0	355.	193.	0.0
12.0	407.1	18.6	1931.	0.0	38.8	37.7	0.057	4.82	0.4654	0.0333	1.00	0.0	0.0	0.0	351.	193.	0.0
13.0	475.0	18.7	1931.	0.0	41.6	40.4	0.061	4.71	0.4655	0.0333	1.00	0.0	0.0	0.0	348.	193.	0.0
14.0	547.6	18.7	1931.	0.0	44.4	43.1	0.065	4.60	0.4656	0.0333	1.00	0.0	0.0	0.0	345.	193.	0.0
15.0	624.9	18.8	1931.	0.0	47.1	45.8	0.069	4.48	0.4657	0.0333	1.00	0.0	0.0	0.0	342.	193.	0.0
16.0	706.7	18.8	1931.	0.0	49.7	48.3	0.073	4.37	0.4658	0.0333	1.00	0.0	0.0	0.0	339.	193.	0.0
17.0	792.8	18.9	1931.	0.0	52.3	50.8	0.077	4.26	0.4658	0.0333	1.00	0.0	0.0	0.0	336.	193.	0.0
ROTATION (TIME= 17.1 AND TAS= 52.5 EAS= 51.0)																	
18.0	883.3	19.0	1931.	0.0	54.8	53.2	0.080	4.13	0.5839	0.0362	2.27	0.0	0.0	0.57	333.	193.	1.27
19.0	977.8	19.0	1931.	2.0	57.2	55.6	0.384	3.95	0.7463	0.0419	4.01	0.0	0.0	0.80	331.	193.	3.01
LIFTOFF (T.E. 19.6 DIST= 1036.6 TAS= 58.6 EAS= 56.9)																	
20.0	1170.4	19.1	1931.	0.2	59.5	57.8	0.087	3.59	0.9061	0.0474	5.70	0.14	14.7	1.05	328.	193.	4.84
21.0	1378.4	19.1	1931.	2.2	61.1	59.4	0.090	1.76	0.9556	0.0540	6.40	2.70	292.0	1.14	327.	193.	8.10
22.0	1581.8	19.2	1931.	4.2	61.5	59.8	0.090	0.02	0.9072	0.0547	6.20	5.69	618.8	1.08	326.	193.	9.89
23.0	1780.3	19.2	1931.	7.2	61.6	59.8	0.090	0.13	0.7793	0.0570	5.10	5.32	578.8	1.00	326.	193.	9.42
24.0	1968.8	19.3	1931.	29.9	61.6	59.9	0.090	0.03	0.7745	0.0586	5.10	5.36	583.9	0.99	326.	193.	9.46
DISTANCE TO 35 FT.= 1946.1																	
25.0	1592.6	19.3	1931.	39.5	61.7	59.9	0.090	0.02	0.7902	0.0605	5.30	5.25	571.5	1.01	326.	193.	9.55
26.0	1694.4	19.4	1931.	48.9	61.7	59.9	0.091	0.10	0.7813	0.0598	5.20	5.15	561.2	1.00	326.	193.	9.35
27.0	1813.2	19.4	1931.	58.3	61.8	60.0	0.091	0.13	0.7812	0.0597	5.20	5.09	555.4	1.00	326.	193.	9.29
28.0	1904.2	19.5	1931.	67.7	61.8	60.0	0.091	0.14	0.7557	0.0577	4.95	5.21	568.7	0.97	325.	193.	9.11
29.0	2008.3	19.5	1930.	76.9	61.9	60.1	0.091	0.32	0.7982	0.0611	5.40	5.16	564.5	1.03	325.	193.	9.56
30.0	2117.4	19.6	1930.	86.5	61.9	60.1	0.091	0.04	0.7727	0.0591	5.10	5.25	576.7	1.00	325.	193.	9.37
31.0	2216.6	19.7	1930.	96.0	62.0	60.1	0.091	0.07	0.7812	0.0597	5.20	5.15	564.0	1.01	325.	193.	9.35
32.0	2320.8	19.7	1930.	105.4	62.0	60.2	0.091	0.09	0.7727	0.0591	5.10	5.16	565.6	1.00	325.	193.	9.26
33.0	2495.2	19.8	1930.	114.8	62.1	60.2	0.091	0.12	0.7812	0.0597	5.20	5.33	552.2	1.01	325.	193.	9.23
34.0	2529.7	19.8	1930.	124.3	62.1	60.3	0.091	0.06	0.7642	0.0584	5.00	5.24	575.3	0.99	325.	193.	9.24
35.0	2634.3	19.9	1930.	133.7	62.2	60.3	0.091	0.13	0.7727	0.0591	5.10	5.05	554.5	1.00	325.	193.	9.15
36.0	2738.9	19.9	1930.	143.2	62.2	60.3	0.091	0.31	0.7727	0.0591	5.10	5.24	578.4	1.03	324.	192.	9.36
37.0	2843.5	20.0	1930.	152.8	62.2	60.3	0.091	0.00	0.7727	0.0591	5.10	5.28	579.9	1.00	324.	192.	9.38
38.0	2948.2	20.0	1930.	162.5	62.2	60.3	0.091	0.00	0.7727	0.0591	5.10	5.27	579.7	1.00	324.	192.	9.37
39.0	3052.8	20.1	1930.	172.2	62.2	60.3	0.091	0.00	0.7727	0.0591	5.10	5.27	579.4	1.00	324.	192.	9.37
40.0	3157.5	20.1	1930.	181.9	62.2	60.3	0.091	0.00	0.7727	0.0591	5.10	5.27	579.3	1.00	324.	192.	9.37
41.0	3262.2	20.2	1930.	191.5	62.3	60.3	0.091	0.31	0.7727	0.0591	5.10	5.26	578.3	1.00	324.	192.	9.36
42.0	3366.9	20.2	1930.	201.2	62.3	60.3	0.091	0.01	0.7727	0.0591	5.10	5.26	578.5	1.00	324.	192.	9.36
43.0	3471.6	20.3	1930.	210.8	62.3	60.3	0.091	0.01	0.7727	0.0591	5.10	5.26	578.3	1.00	324.	192.	9.36
44.0	3576.3	20.3	1930.	220.5	62.3	60.3	0.091	0.01	0.7728	0.0591	5.10	5.26	578.1	1.00	324.	192.	9.35
45.0	3681.1	20.4	1930.	230.1	62.3	60.3	0.091	0.00	0.7728	0.0591	5.10	5.25	578.0	1.00	324.	192.	9.35
46.0	3785.8	20.5	1930.	239.8	62.3	60.3	0.091	0.00	0.7728	0.0591	5.10	5.25	578.0	1.00	324.	192.	9.35
47.0	3890.6	20.5	1929.	249.4	62.3	60.3	0.091	0.00	0.7728	0.0591	5.10	5.25	578.0	1.00	323.	192.	9.35
48.0	3995.4	20.6	1929.	259.1	62.3	60.3	0.092	0.00	0.7728	0.0591	5.10	5.25	577.9	1.00	323.	192.	9.35
49.0	4100.2	20.6	1929.	268.7	62.3	60.3	0.092	0.00	0.7728	0.0591	5.10	5.25	577.9	1.00	323.	192.	9.35
50.0	4205.0	20.7	1929.	278.3	62.3	60.3	0.092	0.00	0.7728	0.0591	5.10	5.25	577.7	1.00	323.	192.	9.35
51.0	4309.9	20.7	1929.	288.0	62.3	60.3	0.092	0.00	0.7728	0.0591	5.10	5.25	577.6	1.00	323.	192.	9.34
52.0	4414.7	20.8	1929.	297.6	62.3	60.3	0.092	0.00	0.7728	0.0591	5.10	5.24	577.3	1.00	323.	192.	9.34

53.0	4519.6	20.8	1929.	307.2	62.3	62.3	0.092	0.00	0.7728	0.0591	5.10	5.24	577.0	1.00	323.	192.	9.34
54.0	4624.4	20.9	1929.	316.9	62.4	60.3	0.092	0.00	0.7728	0.0591	5.10	5.24	576.7	1.00	323.	192.	9.33
55.0	4729.3	20.9	1929.	326.5	62.4	60.3	0.092	0.01	0.7728	0.0591	5.10	5.23	576.4	1.00	323.	192.	9.33
56.0	4834.2	21.0	1929.	336.1	62.4	60.3	0.092	0.01	0.7728	0.0591	5.10	5.23	576.1	1.00	323.	191.	9.33
57.0	4939.1	21.0	1929.	345.7	62.4	60.3	0.092	0.01	0.7728	0.0591	5.10	5.23	575.8	1.00	323.	191.	9.32
58.0	5044.1	21.1	1929.	355.3	62.4	60.3	0.092	0.01	0.7728	0.0591	5.10	5.22	575.5	1.00	323.	191.	9.32
59.0	5149.0	21.1	1929.	364.9	62.4	60.3	0.092	0.01	0.7728	0.0591	5.10	5.22	575.2	1.00	323.	191.	9.32
60.0	5254.0	21.2	1929.	374.5	62.4	60.3	0.092	0.00	0.7728	0.0591	5.10	5.22	575.5	1.00	323.	191.	9.32
61.0	5359.0	21.3	1929.	384.1	62.4	60.3	0.092	0.00	0.7728	0.0591	5.10	5.22	575.4	1.00	323.	191.	9.32
62.0	5464.0	21.3	1929.	393.7	62.4	60.3	0.092	0.00	0.7728	0.0591	5.10	5.22	575.4	1.00	322.	191.	9.32
63.0	5569.0	21.4	1929.	403.3	62.4	60.3	0.092	0.00	0.7689	0.0591	5.10	5.22	575.5	1.00	322.	191.	9.32
64.0	5674.0	21.4	1929.	412.9	62.4	60.3	0.092	0.01	0.7689	0.0591	5.10	5.20	573.6	1.00	322.	191.	9.30
65.0	5779.0	21.5	1929.	422.5	62.4	60.3	0.092	0.01	0.7689	0.0591	5.10	5.20	573.4	1.00	322.	191.	9.30
66.0	5884.0	21.5	1928.	432.0	62.5	60.3	0.092	0.01	0.7689	0.0591	5.10	5.20	573.9	1.00	322.	191.	9.30
67.0	5989.1	21.6	1928.	441.6	62.5	60.3	0.092	0.01	0.7689	0.0591	5.10	5.20	573.5	1.00	322.	191.	9.30
68.0	6094.2	21.6	1928.	451.1	62.5	60.3	0.092	0.01	0.7689	0.0591	5.10	5.19	572.9	1.00	322.	191.	9.29
69.0	6199.2	21.7	1928.	460.7	62.5	60.3	0.092	0.01	0.7689	0.0591	5.10	5.19	573.1	1.00	322.	191.	9.29
70.0	6304.3	21.7	1928.	470.2	62.5	60.3	0.092	0.01	0.7689	0.0591	5.10	5.19	573.1	1.00	322.	191.	9.29
71.0	6409.4	21.8	1928.	479.8	62.5	60.3	0.092	0.01	0.7689	0.0591	5.10	5.19	573.0	1.00	321.	191.	9.29
72.0	6514.5	21.8	1928.	489.3	62.5	60.3	0.092	0.01	0.7689	0.0591	5.10	5.19	572.8	1.00	321.	191.	9.29
73.0	6619.6	21.9	1928.	498.8	62.5	60.3	0.092	0.01	0.7689	0.0591	5.10	5.19	572.4	1.00	321.	191.	9.28
74.0	6724.8	21.9	1928.	508.4	62.5	60.3	0.092	0.01	0.7689	0.0591	5.10	5.18	571.9	1.00	321.	191.	9.28
75.0	6829.9	22.0	1928.	517.9	62.5	60.3	0.092	0.01	0.7689	0.0591	5.10	5.18	572.1	1.00	321.	191.	9.28
76.0	6935.0	22.0	1928.	527.4	62.5	60.3	0.092	0.01	0.7689	0.0591	5.10	5.18	572.1	1.00	321.	191.	9.28
77.0	7040.2	22.1	1928.	537.0	62.5	60.3	0.092	0.01	0.7689	0.0591	5.10	5.18	571.9	1.00	321.	190.	9.28
78.0	7145.3	22.2	1928.	546.5	62.5	60.3	0.092	0.01	0.7689	0.0591	5.10	5.18	571.5	1.00	321.	190.	9.27
79.0	7250.5	22.2	1928.	556.0	62.5	60.3	0.092	0.01	0.7689	0.0591	5.10	5.18	571.8	1.00	321.	190.	9.28
80.0	7355.7	22.3	1928.	565.5	62.5	60.3	0.092	0.01	0.7689	0.0591	5.10	5.17	571.1	1.00	321.	190.	9.27
81.0	7460.9	22.3	1928.	575.0	62.5	60.3	0.092	0.01	0.7689	0.0591	5.10	5.17	571.0	1.00	321.	190.	9.27
82.0	7566.1	22.4	1928.	584.5	62.5	60.2	0.092	0.01	0.7689	0.0591	5.10	5.17	570.8	1.00	321.	190.	9.27
83.0	7671.3	22.4	1928.	594.1	62.6	60.2	0.092	-0.00	0.7732	0.0594	5.15	5.16	570.5	1.00	321.	190.	9.31
84.0	7776.5	22.5	1928.	603.6	62.6	60.2	0.092	0.01	0.7689	0.0591	5.10	5.17	571.0	1.00	320.	190.	9.27
85.0	7881.7	22.5	1927.	613.1	62.6	60.2	0.092	0.00	0.7732	0.0594	5.15	5.16	569.8	1.00	320.	190.	9.30
86.0	7987.0	22.6	1927.	622.6	62.6	60.2	0.092	0.01	0.7689	0.0591	5.10	5.16	570.6	1.00	320.	190.	9.26
87.0	8092.2	22.6	1927.	632.1	62.6	60.2	0.092	0.01	0.7689	0.0591	5.10	5.16	570.2	1.00	320.	190.	9.26
88.0	8197.5	22.7	1927.	641.6	62.6	60.2	0.092	0.00	0.7732	0.0594	5.15	5.15	569.0	1.00	320.	190.	9.30
89.0	8302.7	22.7	1927.	651.1	62.6	60.2	0.092	-0.00	0.7732	0.0594	5.15	5.15	569.4	1.00	320.	190.	9.30
90.0	8408.0	22.8	1927.	660.6	62.6	60.2	0.092	0.01	0.7689	0.0591	5.10	5.13	567.4	1.00	320.	190.	9.25
91.0	8513.3	22.8	1927.	670.0	62.6	60.2	0.092	0.01	0.7689	0.0591	5.10	5.15	569.4	1.00	320.	190.	9.25
92.0	8618.6	22.9	1927.	679.5	62.6	60.2	0.092	-0.00	0.7732	0.0594	5.15	5.15	568.9	1.00	320.	190.	9.29
93.0	8723.9	22.9	1927.	689.0	62.6	60.2	0.092	0.01	0.7689	0.0591	5.10	5.15	569.1	1.00	320.	190.	9.24
94.0	8829.2	23.0	1927.	698.5	62.6	60.2	0.092	0.00	0.7732	0.0594	5.15	5.14	568.0	1.00	320.	190.	9.28
95.0	8934.5	23.0	1927.	707.9	62.6	60.2	0.092	0.00	0.7732	0.0594	5.15	5.14	568.2	1.00	320.	190.	9.29
96.0	9039.8	23.1	1927.	717.4	62.6	60.2	0.092	-0.00	0.7732	0.0594	5.15	5.14	568.6	1.00	319.	190.	9.29
97.0	9145.2	23.2	1927.	726.9	62.6	60.2	0.092	-0.00	0.7732	0.0594	5.15	5.14	568.2	1.00	319.	189.	9.29
98.0	9250.5	23.2	1927.	736.4	62.6	60.2	0.092	-0.00	0.7732	0.0594	5.15	5.14	568.4	1.00	319.	189.	9.29
99.0	9355.8	23.3	1927.	745.8	62.6	60.2	0.092	-0.00	0.7732	0.0594	5.15	5.14	568.2	1.00	319.	189.	9.29
100.0	9461.2	23.3	1927.	755.3	62.6	60.2	0.092	0.00	0.7732	0.0594	5.15	5.13	567.8	1.00	319.	189.	9.28
101.0	9566.5	23.4	1927.	764.8	62.6	60.2	0.092	0.00	0.7732	0.0594	5.15	5.13	567.8	1.00	319.	189.	9.28
102.0	9671.9	23.4	1927.	774.2	62.6	60.2	0.092	0.00	0.7732	0.0594	5.15	5.13	567.5	1.00	319.	189.	9.28
103.0	9777.3	23.5	1927.	783.7	62.6	60.2	0.092	-0.00	0.7732	0.0594	5.15	5.13	567.6	1.00	319.	189.	9.28
104.0	9882.6	23.5	1926.	793.1	62.6	60.2	0.092	0.00	0.7732	0.0594	5.15	5.13	567.3	1.00	319.	189.	9.28
105.0	9988.0	23.6	1926.	802.6	62.6	60.1	0.092	-0.00	0.7732	0.0594	5.15	5.13	567.5	1.00	319.	189.	9.26
106.0	10093.4	23.6	1926.	812.0	62.6	60.1	0.092	-0.00	0.7732	0.0594	5.15	5.13	567.3	1.00	319.	189.	9.28
107.0	10198.7	23.7	1926.	821.5	62.6	60.1	0.092	0.00	0.7732	0.0594	5.15	5.12	566.7	1.00	319.	189.	9.27
108.0	10304.1	23.7	1926.	830.9	62.6	60.1	0.092	0.00	0.7732	0.0594	5.15	5.12	566.5	1.00	319.	189.	9.27
109.0	10409.5	23.8	1926.	840.4	62.6	60.1	0.092	0.00	0.7732	0.0594	5.15	5.11	565.9	1.00	318.	189.	9.26
110.0	10514.9	23.8	1926.	849.8	62.7	60.1	0.092	0.01	0.7732	0.0594	5.15	5.11	565.1	1.00	318.	189.	9.25
111.0	10620.3	23.9	1926.	859.2	62.7	60.1	0.092	0.01	0.7732	0.0594	5.15	5.10	564.1	1.00	318.	189.	9.25
112.0	10725.7	23.9	1926.	868.6	62.7	60.1	0.092	0.01	0.7732	0.0594	5.15	5.10	564.6	1.00	318.	189.	9.25
113.0	10831.1	24.0	1926.	878.0	62.7	60.1	0.092	0.01	0.7732	0.0594	5.15	5.10	564.2	1.00	318.	189.	9.25
114.0	10936.6	24.0	1926.	887.4	62.7	60.1	0.092	0.01	0.7732	0.0594	5.15	5.09	563.8	1.00	318.	189.	9.24
115.0	11042.0	24.1	1926.	896.8	62.7	60.1	0.092	0.01	0.7732	0.0594	5.15	5.10	564.5	1.00	318.	189.	9.25
116.0	11147.5	24.2	1926.	906.2	62.7	60.1	0.092	0.01	0.7732	0.0594	5.15	5.09	563.8	1.00	318.	189.	9.24
117.0	11252.9	24.2	1926.	915.4	62.7	60.1	0.092	0.01	0.7732	0.0594	5.15	5.09	563.7	1.00	318.	188.	9.24
118.0	11358.4	24.3	1926.	925.0	62.7	60.1	0.092	0.01	0.7732	0.0594	5.15	5.09	563.6	1.00	318.	188.	9.24
119.0	11463.9	24.3	1926.	934.4	62.7	60.1	0.092	0.01	0.7732	0.0594	5.15	5.09	563.3	1.00	318.	188.	9.23
120.0	11569.4	24.4	1926.	943.8	62.7	60.1	0.092	0.01	0.7732	0.0594	5.15	5.08	562.9	1.00	318.	188.	9.23
121.0	11674.9	24.4	1926.	953.2	62.7	60.1	0.092	0.01	0.7732	0.0594	5.15	5.08	563.2	1.00	318.	188.	9.23
122.0	11780.4	24.5	1926.	962.5	62.7	60.1	0.092	0.01	0.7732	0.0594	5.15	5.08	562.6	1.00	317.	188.	9.23
123.0	11885.9	24.5	1925.	971.9	62.7	60.1	0.092	0.01	0.7732	0.0594	5.15	5.08	562.6	1.00	317.	188.	9.23
124.0	11991.5	24.6	1925.	981.3	62.7	60.1	0.092	0.01	0.7732	0.0594	5.15	5.08	562.5	1.00	317.	188.	9.22
125.0	12097.0	24.6	1925.	990.7	62.7	60.1	0.092	0.01	0.7732	0.0594	5.15	5.07	562.1	1.00	317.	188.	9.22
126.0	12202.6	24.7	1925.	1000.0	62.7	60.1	0.092	0.01	0.7732	0.0594	5.15	5.08	563.1	1.00	317.	188.	9.23

ALL ENGINE DISTANCE TO 35 FT. (L) = 1546.1 FEET
FAR 25 T.O. DISTANCE (1.15XL) = 1775.7 FEET
ALL ENGINE DISTANCE TO 50 FT. = 1708.6 FEET

AT END OF TAKEOFF PHASE
TIME= 0.235 HRS FUEL USED= 25. LBS WEIGHT= 1925. LBS ALT.= 1000. FT.

+++++START OF INPUT FOR MISSION DESCRIPTION
ISFG=3.0

```
   CLIMB TO   10000. FT. AT MAXIMUM RATE OF CLIMB

 TIME    RANGE    FUEL USED   WEIGHT    ALT.      TAS      EAS      MACH     MACH      CL        CD       ALPHA    GAMMA   FUS. ANGLE    R/C      THRUST    FUEL FLOW
 (HRS)   (NM)     (LBS)       (LBS)     (FT)     (KTS)    (KTS)    NO.      DIV                          (DEG)    (DEG)   (DEG)         (FPM)    (LBS)     (LB/HR)

 0.235      0.       25.      1925.     1000.     73.      72.    0.111    0.649   0.5443   0.0435    2.43     5.54     6.97         715.      339.      212.
 0.258      2.       32.      1920.     2000.     74.      72.    0.113    0.649   0.5432   0.0435    2.42     5.22     6.63         683.      329.      206.
 0.283      3.       35.      1915.     3000.     75.      72.    0.115    0.650   0.5421   0.0434    2.40     4.93     6.33         656.      319.      200.
 0.308      5.       40.      1910.     4000.     76.      72.    0.117    0.650   0.5408   0.0433    2.39     4.65     6.04         628.      309.      195.
 0.335      7.       45.      1905.     5000.     78.      72.    0.119    0.650   0.5396   0.0433    2.37     4.38     5.75         600.      299.      189.
 0.362     10.       50.      1900.     6000.     76.      70.    0.117    0.646   0.5756   0.0453    2.80     4.34     6.14         584.      292.      183.
 0.391     12.       55.      1895.     7000.     76.      69.    0.118    0.644   0.5869   0.0460    2.93     4.06     5.99         549.      283.      178.
 0.421     14.       61.      1889.     8000.     77.      68.    0.119    0.643   0.5982   0.0467    3.06     3.85     5.91         522.      274.      173.
 0.453     17.       66.      1884.     9000.     77.      67.    0.120    0.642   0.6096   0.0474    3.20     3.63     5.83         495.      266.      168.
 0.487     19.       72.      1878.     10000.    78.      67.    0.121    0.643   0.6213   0.0482    3.33     3.42     5.75         469.      258.      163.

   END OF CLIMB TO   10000. FT
TIME=  0.487 HRS   FUEL USED=      72. LBS   WEIGHT=    1878. LBS   RANGE=      19. NM

*****START OF INPUT FOR MISSION DESCRIPTION
      ISEG=9,*

*****START OF INPUT FOR CONTROL
      NPC=1,NSC=8,IDC=0,*

*****START OF INPUT FOR RESERVE OR RANGE INFO.
      KAERO=1,RESSF=0.,*

*****START OF INPUT FOR CONTROL
      NPC=7,NSC=8,IDC=0,
      EM=.142,ALT=10000.,*


SUMMARY OF CRUISE LIFT-WEIGHT BALANCE
  ANGLE OF ATTACK(DEGREES)     3.384 LIFT     1878.1 L/D    11.713 ALTITUDE    10000.0


SUMMARY OF CRUISE LIFT-WEIGHT BALANCE
  ANGLE OF ATTACK(DEGREES)     0.513 LIFT     1574.2 L/D    10.694 ALTITUDE    10000.0

 ************************************************************************************************

  CRUISE SUMMARY

 TIME    RANGE    FUEL USED   WEIGHT    ALT.      TAS      EAS      CL       ANGLE ATTACK   FUS. ANGLE    L/D      MACH NO.   MACH DIV   FUEL FLOW    BREG FACT
 (HRS)   (NM)     (LBS)       (LBS)     (FT)     (KTS)    (KTS)                (DEG)         (DEG)                                          (LB/HR)      (NM)
 0.487     19.       72.      1878.     10000.    91.      78.    0.4570    3.384          0.38        11.710    0.142      0.659        106.      1612.      BEGIN
 3.456    299.      376.      1574.     10000.    91.      78.    0.3831    0.513         -0.49        10.694    0.142      0.668         99.      1443.      END

     RESERVE FUEL =        0. LBS.


 ************************************************************************************************

*****START OF INPUT FOR CONTROL
      NPC=1,NSC=9,IDC=0,*

*****START OF INPUT FOR COSTING INFORMATION
      WCPM=114.965,NCADS=1,HIP=.03,CLI=300.,PI=.1,CRWDH=0.,CINP=100.,
      WCPMT=91.0,
      MFI=373.,THW=10.,UCSENG=25.,TBO=3300.,SPPM=60.,ALR=11.82,FCSF=.70,
      DYR=7.5,UCSENG=26.34142,
      RI=0.,SRPM=0.,
      AIR=5.50,
      *

*****START OF INPUT FOR CONTROL
      NPC=2,NSC=9,IDC=0,*
```

```
                --- COST DATA ---
ENGINES      NUMBER =      1.  TYPE=      7
EMPTY WEIGHT=     1174. LBS              MAX.CRUISE SPEED=     91. KNOTS
CONSUMER PRICE=  37603. DOL.        BASIC PRICE=  30601. DOL.
                                    ADD. EQUIPMENT COST=   7002. DOL.

DIRECT LABOR (  313.MHRS.)          1722.
LABOR OVERHEAD(132.PCT)             2271.
AIRFRAME-MATERIALS                   455.
PURCHASED EQUIP.                   11993.
   ($/ENG.= 11569.)
   ($/PROP=     0.)
   (OTHER =   421.)
                                   16437.  SUB-TOTAL
ENG,TL,SALES,G-A( 31.PCT)           5092.
                                   21529.  MANUFACTURING COST
FACTORY PROFIT(  9.PCT)             2010.
                                   23539.  DEALER COST
DEALER-DIST. MARKUP( 30.PCT)        7062.
                                   30601.  BASIC PRICE

ILF225I PROGRAM INTERRUPT    OLD PSW IS    071D0000B2125BC6          REGISTER CONTAINED    788ACD5090800000
 **********************************************************************************************

RANGE=      289. N.M.     BLOCK FUEL=      376. LBS     BLOCK TIME=  3.456 HRS.
FUEL RATE= 16.2 GPH.      TBO= 3000. HRS.     HOURS/INSP.=  300. HRS.

VARIABLE COST     (DOL/HR)          FIXED COST       (DOL/YR)
   FUEL+OIL         11.49             STORAGE            0.
   INSP.+MAIN.       3.33             INSURANCE       1428. (HULL 3.0PCT)
   OVERHAUL RES.     1.46             DEPRECIATION    4011. ( 8.YR-20.PCT)
   OTHER             0.0              OTHER              0.
                                      CREW               0.(OVERHEAD  0.PCT)
                                      FAA TAX           25.
                    16.29 TOTAL                         5464. TOTAL

UTILIZATION(HRS/YR)      100.    200.    300.    400.    500.    800.
TOTAL OPR.COST(DOL/HR)  70.93   43.61   34.55   29.95   27.22   23.12

*****START OF INPUT FOR CONTROL
END OF INPUT DATA, JOB COMPLETE.
```

BLOCK SPEED $V_B = \frac{289}{3.456} = 83.62$ KT

DOC ($/NMi) = DOC ($/HR)/$V_B = \frac{34.50}{83.62} = .41.26$ (FOR 300 HR/YR UTILIZATION)

5.0 PHASE - CONCLUSIONS

5.1 FLYING QUALITIES OF BASELINE

The final design of the Cessna baseline is, except for the powerplant, a conventional aircraft. There is, for example, no reason to incorporate full span Fowler flaps since the wing has been sized to allow landing with the flaps up. Neither are spoilers needed since the flaps do not occupy the entire wing trailing edge, nor is the wing of such high aspect ratio that ailerons cannot be used because of the large torsional wing moments they produce.

In light of the above, normal design procedures can be expected to yield satisfactory flying qualities. A detailed analysis of handling characteristics then would not add materially to the value of this study and the time available was allocated to other tasks that appeared to offer information more pertinent to the purpose of the study.

The tail surfaces are sized according to the trend equations of Section 3.2.5.

The values used in these equations are:

h_f = 52.5 in

w_f = 44 in

Δx = 8 in

l_f = 268 in

S = 137.3 ft^2

$\bar{c}_W$ = 51.693 in

b_W = 385.08 in

l_H = 135 in

l_V = 138 in

x aft cg = 32.29 % MAC

Based on the trend equations this yields:

$\bar{V}_H$ = .6377

$\bar{V}_V$ = .0447

S_H = 33.524 ft^2

S_V = 17.127 ft^2

x aft cg limit = 32.46 % MAC

5.2 COMPARISON OF BASELINE TO RECIPROCATING ENGINE POWERED LIGHT AIRCRAFT

Table 7 shows a comparison between the characteristics of the Cessna baseline as designed by Cessna's method and by the GASP. These characteristics are also compared to the Commuter II version of the 1976 Cessna 150. (The avionics package of the Commuter II is a very popular option and as such was chosen for the baseline.)

The gross weight of the GASP estimate is substantially larger than that estimated by Cessna's method. This is due in part to the higher fuel consumption of the larger engine (376 vs. 337 pounds or a $\Delta W = 39$) and in part to the higher empty weight. (1174 vs. 1003 pounds or a $\Delta W = 171$). Of this latter figure 48 pounds can be attributed to the higher gross weight and 3 pounds to the larger engine. The remainder (171-48-3=120) is attributed to the difference in methods.

The difference in wing loading and engine size between the Cessna sized airplane and that sized by the GASP is believed to be due, in part, to the differences in drag between the two methods. Comparison of Fig. 40 to Fig. 49 shows a large difference in the slope of the TOFL = 1700 ft line that is also shifting the minimum DOC point (as defined by the GASP) to lower wing loadings and lower thrust levels.

The baseline plane (as estimated by Cessna's method) is heavier than the Cessna 150 by 140 pounds. Yet due to the lighter engine the baseline enjoys a significantly lower empty weight (1003 vs. 1122 pounds). Although the baseline carries 47 pounds more payload, the difference in gross weight is mostly due to the higher fuel load required (337 vs. 125 pounds).

Compared to the Cessna 150 the trainer is at a considerable economic disadvantage. The price is from 38% to 101% above the 150's (depending on the method used to estimate it). The DOC shows a 76% to 119% increase over the 150. There is no reason from this comparison to believe that the turbofan powered plane could compete in today's market against the trainers currently available.

A breakdown of the DOC (as calculated by Cessna's method) is shown in Table 8. This indicates that the turbofan is approximately equal to the 150 in many areas. However, in the areas of engine periodic maintenance, fuel cost, and depreciation the turbofan aircraft is considerably more expensive to operate (the fuel cost for the 150 was calculated for a fuel price of \$.75/gal; i.e. 5¢ per gal higher than the price of jet fuel). The result, as mentioned above, is a DOC 76% higher than the 150's.

TABLE 7

COMPARISON OF THE 2-PLACE TURBOFAN POWERED TRAINER
TO A RECIPROCATING POWERED LIGHT AIRCRAFT

	2-Place Turbofan Trainer		Cessna 150
	As Optimized by Cessna Methodology	As Optimized by GASP	1976 Model Commuter II
Price $	25854	37603	18750
Direct Operating Cost $/NMI	.332	.413	.189
Weight (lbs)			
Gross	1740	1950	1600
Empty	1003	1174	1122
Fuel	337	376	135 (125)
Payload	400	400	343 (353)
Size			
Length Overall (ft)	25.42	22.33	23.92
Wing Area (ft^2)	137.3	200	160
Tail Area (ft^2)			
Horizontal	33.5	51.9	30.9
Vertical	17.1	43.2	11.6
Performance			
Cruise Speed (kts)	104	91	106
Cruise Alt (ft)	10000	10000	7000
Endurance (hrs)	3.5	3.5	3.8 (3.5)
Range (n.mi)	343	290	390 (360)
TOFL (ft)	1700	1700	1385
Stall Speed (kts) (flaps up)	50.0	42.8	48.0
Engine (Uninstalled)	415 (lb SLS thrust Garrett Turbofan)	463	100 HP (@ 2700RPM) Continental O-200A

NOTE: The numbers in brackets indicate the effect, on the Cessna 150's payload and range, of restricting the fuel weight to that required to match the 3.5 hr. endurance requirements of the baseline design. These numbers are shown in order to facilitate comparisons between the two aircraft.

TABLE 8

COMPARISON OF THE COMPONENTS OF THE DIRECT OPERATING COST

	2-Place Turbofan	Cessna 150
Engine periodic maintenance cost	.061	.017
Engine overhaul cost	.013	.012
Airframe maintenance cost	.010	.010
Hull insurance	.021	.016
Liability insurance	.009	.008
Fuel cost	.101	.044
Oil cost	0	.0004
Depreciation	.117	.082
DOC ($/N MI)	.332	.189

5.3 EVALUATION OF GASP

5.3.1 Methodology

5.3.1.1 Lift

The GASP routines utilize empirically developed charts from a paper by K. L. Sanders (ref. 8) to determine the maximum lift coefficient. These charts are the result of an effort to correlate the data from a large number of independent wind tunnel tests which were not systematically developed. Close scrutiny of some of the curves presented by Sanders yields some startling results.

Figure 50 is a reproduction of part of Figure 5a in Sanders' paper. It represents his interpretation of maximum lift coefficient of the wing as a function of aspect ratio. The reference condition is supposedly for aspect ratio = 12, taper ratio = 1., thickness ratio = 0.10, sweepback = 0° and test Reynolds number = $6X10^6$; however, the reference $C_{L_{MAX}}$ quoted is from two-dimensional data. Two references are given for the curve for straight and swept wings: SAAB TN 15(Ref. 7)and NASA CR 421(Ref. 15). The NASA CR deals only with low aspect ratios while the SAAB TN analyzes aspect ratios up to 7. Fig. 51 is a partial reproduction of Fig. 7 in the SAAB TN. The data which Sanders used is for a thickness ratio = 0.12 at 1 to $3X10^6$ Reynolds number. Yet his curve is supposed to represent a thickness ratio = 0.10 at $6X10^6$ Reynolds number. Furthermore, no references could be found in the Sanders paper which contain data for aspect ratios in the range from 7 to 12. Therefore, the value of Sander's data is questionable.

Fig. 52 was produced using data compiled in DATCOM and indicates that for swept wings a peak in $C_{L_{MAX}}$ may occur around an aspect ratio of six. Even this data is not conclusive, however, since the results came from unrelated wind tunnel studies

5.3.1.2 Drag

The parasite drag estimation method used by the GASP program is essentially the same as the method described in Ref. 16. Although the method is quite general and complex the report shows a reasonable correlation of calculated versus wind tunnel drag for only one light twin engine airplane (the Piper Twin Commanche-pre tip tank model); however, further correlation against in-flight performance of the aircraft and against a variety of existing general aviation aircraft would be desirable before justifying the use of a method as complex as that of the GASP.

The drag due to lift estimation method used by the GASP program for wings with zero leading edge sweep defines the Oswald efficiency factor as:

$$e=1-.045AR^{.068}$$

This is an exclusive function of aspect ratio not accounting for the effects of the propeller slipstream (where appropriate) nor for the effects of variations in configuration parasite drag. Experience indicates that omission of these two parameters could lead to underestimation of induced drag.

The inputs in subroutine AERO that control drag have defaults for both the fuselage form factor (CKF) and for an "increment in equivalent flat plate area" (DELFE). It is understood, however, that the purpose of DELFE is to allow the user to input his estimate of fuselage drag (if known). In which case he should zero out CKF. If he uses CKF, however, he should zero out DELFE. This being the case both terms should not have default values; the designer who wishes to use them and who is unfamiliar with the program will probably wind up with excessive fuselage drag not realizing that one or the other of these variables must be eliminated. Cessna recommends that the default value of DELFE be changed to zero.

The user is given the option of modifying C_{D_o} by appropriate inputs of the form factors or the incremental flat plate areas. He is given no option, though, for modifying "e". Such an option should be provided.

5.3.1.3 Weights

Tables 9 and 10 (taken from the GASP preliminary documentation) present the data points used to derive the GASP weight methods for estimating the landing gear and control system weights respectively. In the two tables the airplanes used have gross weights ranging from over 12000 pounds up to 732000 pounds. These planes do not fall in the general aviation category. Considering the results noted in Section 4.1.1.3 these components evidently are a lower percentage of the gross weight on these aircraft than they are on general aviation aircraft.

The GASP equation for determining wing weight is unnecessarily complex for general aviation designs. The range of data used to develop the equation is shown in Figure 53. Again the weights used in that graph are for aircraft larger than those normally classed as general aviation.

The range of possible values suggested for some of the inputs in subroutine WGHT are so large that they often require sophisticated guesswork or advance knowledge of the answer. Taking SKWW (wing weight coefficient) for example, values suggested in the preliminary GASP documentation range from 111 for the Cessna 150 to 235 for the Cessna 340. However, SKWW is supposed to equal 220x"a" which implies that suggested values of "a" range from .5 to 1.1. Examining Fig. 53 again shows that most all data is covered by "a's" from .9 to 1.1. It was for this reason that, Cessna tried to bias the GASP result to match Cessna's weight analysis. This was the one case in which Cessna manipulated the input; otherwise, as stated in Sec. 4.32, there was no effort to modify the input to match Cessna's analysis.

The GASP weight trend equations are not derived from weight data of a sufficient number of general aviation aircraft. Simpler weight equations of the form of those outlined in Sec.3.2.4 are recommended

5.3.1.4 Tail Size

The trend equations, used by the GASP to size the vertical and horizontal tails, are significantly different from those used by Cessna. Cessna's trend equations are outlined in Section 3.2.5. (The GASP trends are shown on Fig 22 for the vertical tail and Fig 54 for the horizontal.) In developing these equations Cessna failed to verify the effect of horizontal tail height that is shown in the GASP equations. A comparison of Fig 25 to Fig 54 shows that the inclusion of the cg term significantly reduces the data scatter

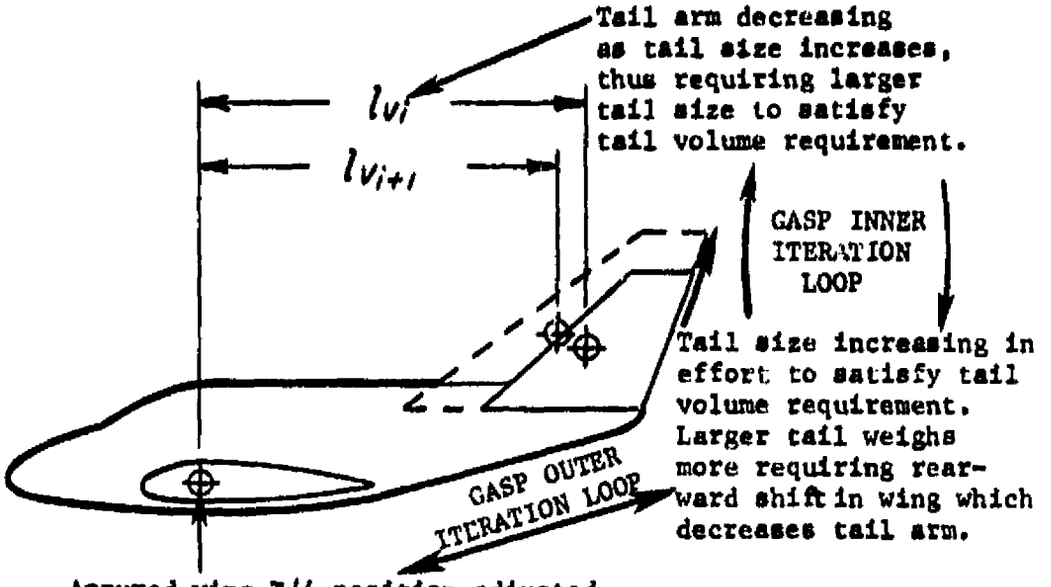
It is understood that the vertical tail size, from which the GASP equations were developed, included the areas of the dorsal and vertical fins (if any). In practice,the dorsal fins are often designed by considerations of aesthetics in addition to aerodynamics. The presence of a dorsal contributes a positive, beneficial effect on the directional handling qualities of a plane However, the size and geometry of these fins (within reasonable limits) are of secondary importance. Therefore, it is recommended that this area not be included in the tail areas.

The present GASP tail volume equations are inadequate; Cessna recommends that they be reworked along the lines indicated in Section 3.2.5. It should be noted that the constants in the equations of Sec. 3.2.5 apply only to single engine aircraft with conventional elevator-stabilizer designs.

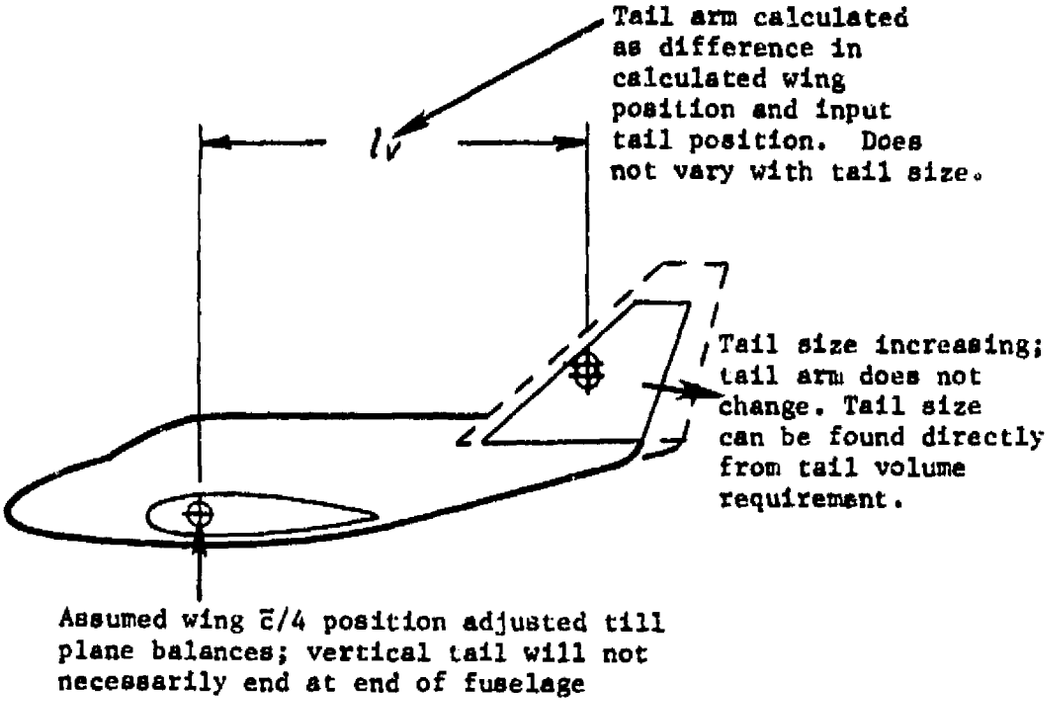
The input of the tail arms to the GASP can also be improved. If LCWING = 0, the tail arm is calculated from input values of $\bar{c}_W/l_H$ and b_W/l_V. From the initial 3-view the designer can read values of $l_H$and l_V. And, unless the initial 3-view is unusually inaccurate, these values will not change significantly during the sizing process. Not so the wing area (and henceforth $\bar{c}_W$ and b_W). The initial estimate of the designer can be in error by as much as 50%. Therefore, inputting the ratios causes the tail arms to change drastically as the wing is sized by the program. Where, in actuality, the arms change little if any with wing size. The input should consist of these two arms in dimensional form, not ratios.

If LCWING = 1 (the balance option), however, the program tries to calculate the tail arms based on the trailing edge of the vertical being at the end of the fuselage. This could lead to gross exaggerations; in one test run done for this study the tail size iteration loop generated horizontal tail areas of over 1000 ft^2. The tail arm during a balance exercise should be calculated as the difference between the calculated fuselage station of the wing quarter chord and the input fuselage station of the tail quarter chord. These methods are illustrated in sketch (b).

PRESENT GASP METHOD


Tail arm decreasing as tail size increases, thus requiring larger tail size to satisfy tail volume requirement.
l_{v_i}
$l_{v_{i+1}}$
GASP INNER ITERATION LOOP
Tail size increasing in effort to satisfy tail volume requirement. Larger tail weighs more requiring rearward shift in wing which decreases tail arm.
GASP OUTER ITERATION LOOP
Assumed wing $\bar{c}/4$ position adjusted till plane balances; tail located by placing trailing edge of vertical at end of fuselage.

PROPOSED GASP METHOD


Tail arm calculated as difference in calculated wing position and input tail position. Does not vary with tail size.
l_v
Tail size increasing; tail arm does not change. Tail size can be found directly from tail volume requirement.
Assumed wing $\bar{c}/4$ position adjusted till plane balances; vertical tail will not necessarily end at end of fuselage

Sketch (b)

5.3.1.5 Price and Direct Operating Cost

The GASP method of estimating airplane cost begins with estimating the manhours required to build the plane and multiplying this by a user specified labor rate. Various overhead rates for labor overhead, engineering, sales, etc. are then added. It is recommended that additional flexibility be programmed into GASP in order to provide the user with the opportunity of determining overhead based on his own bookkeeping procedures.

Further, different methods are used to calculate the DOC for different classes of aircraft and the methods will vary from one manufacturer to another. (For example, some consider storage costs in calculating DOC while others do not.) A different method of calculating DOC could have changed the optimized aircraft of this study since it was optimized relative to DOC. The GASP user must be given flexibility to calculate the DOC compatible with his methods and the class of plane being sized.

Further, the trend equation used by the GASP for calculating avionics cost should be used only as a default feature. As outlined in Section 3.1.2 the avionics cost should be evaluated as a separate item and the cost held constant despite the program sizing (or costing) of the basic plane.

Lastly, as outlined in Section 3.1.2, Cessna correlates cost against a weight-speed product for its single engine aircraft. There is no class where cost is correlated only with weight as in the GASP.

5.3.1.6 Fuselage Description

As the GASP now stands, the fuselage dimensions are input in terms of length/diameter ratios (ELODN, ELODT) where the diameter (taken to be the same as the width) is calculated from seat and aisle widths (SAB, WS, AS, WAS). While this is adequate for default values when the program is being used (for example) in a wing geometry trade study, in which the fuselage is of secondary effect, it is inadequate when the program is being used to size an airplane. It is also a difficult format in which to put the data if an effort is being made to evaluate a given design.

Further, the diameter derived by the GASP is used to estimate the fuselage wetted area as if the fuselage were circular. Since this is seldom the case and since the depth usually exceeds the width, the error in calculating the wetted area can be significant.

Most designs begin with a 3-view; therefore, Cessna recommends that the GASP be reworked to allow the user to input the fuselage dimensions directly from this drawing.

5.3.1.7 Performance Methods

Performance as estimated by GASP seems compatible to Cessna methods. Some thought should be given to modifying the GASP Breguet range equation as discussed in Section 3.2.6.1 (b).

From Ref. 8. High Lift Devices, A Weight and Performance Trade Off. by K. L. Sanders, SAWE Paper 761, 1969.

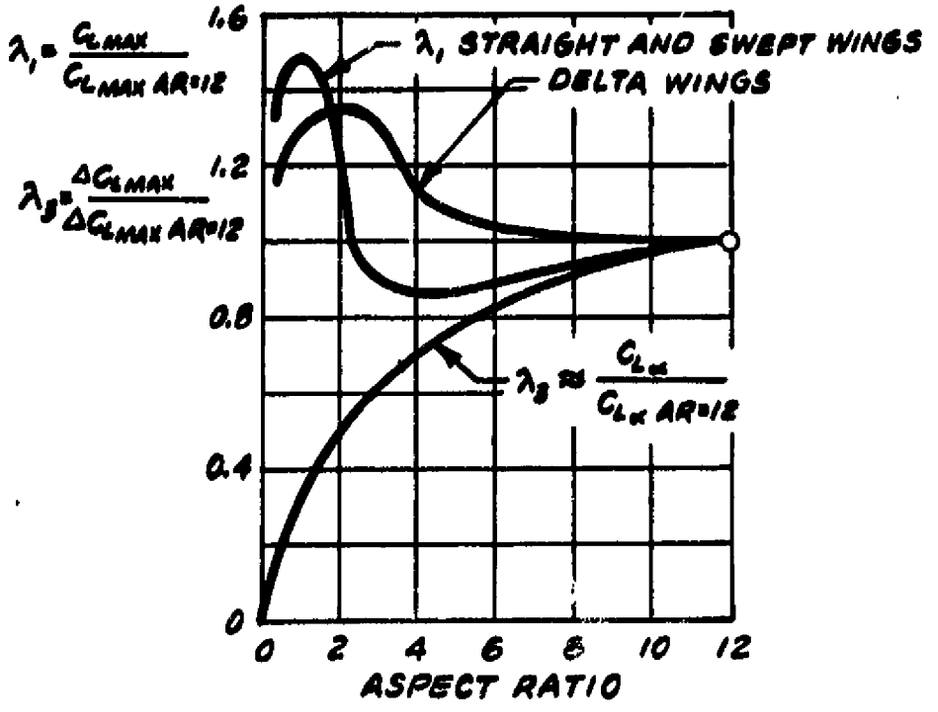


Figure 50. Correction Factors.

From Ref. 7. Summary of Stalling Characteristics and Maximum Lift of Wings at Low Speed by H.O. Palme. SAAB TN15, 1953.

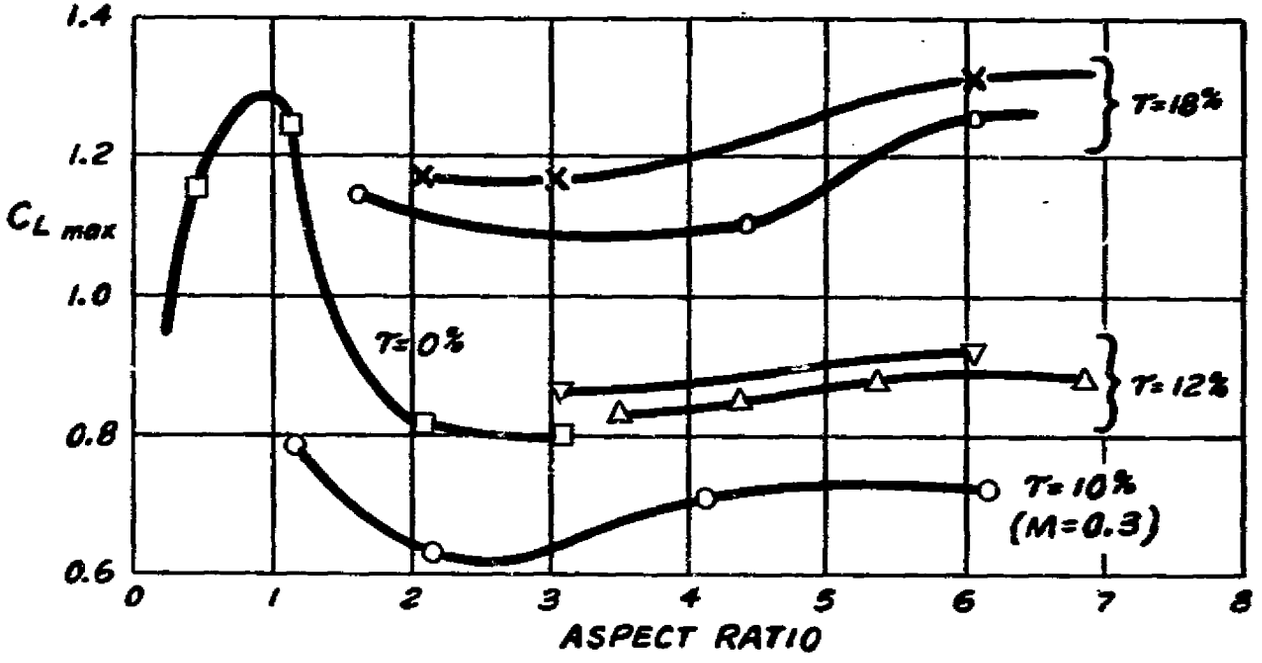


Figure 51. The Influence of Aspect Ratio on $C_{L_{MAX}}$ for Straight Wings.

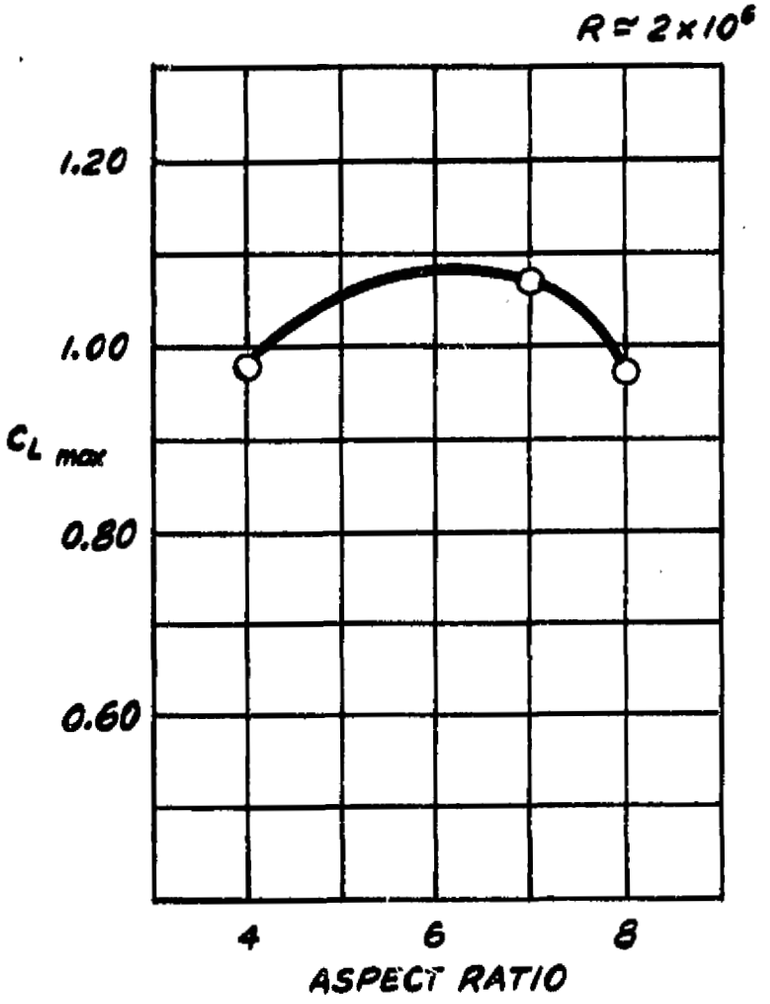


Figure 52. The Influence of Aspect Ratio on $C_{L_{MAX}}$ for Swept Wings.

TABLE 9
LANDING GEAR WEIGHTS

Aircraft	Gross Weight (lb)	Total Gear Weight (lb)	Percent of Gross Weight
Military			
DHC-4*	28,500	1,398	0.049
F-27	42,000	1,884	0.045
Breguet 941*	46,000	2,626	0.057
DHC-5*	41,000	1,800	0.044
C-123B	54,000	2,331	0.043
C-118	107,000	3,895	0.036
C-130B*	135,000	4,824	0.036
C-130E*	155,000	4,939	0.032
C-124C	185,000	11,700	0.063
C-133A	275,000	10,635	0.039
C-141	318,000	10,357	0.033
C-5A	732,000	32,711	0.045
Commercial			
Gulfstream	35,100	1,237	0.035
Convair 440	49,100	2,158	0.044
Boeing 737-100	102,000	4,372	0.043
Boeing 727-100	161,000	7,211	0.044
Convair 880	184,500	6,933	0.038
Boeing 707-320	336,000	12,982	0.038
VTOL			
XV-5A	12,500	482	0.038
XV-4B	12,500	389	0.031
CL-84	12,600	369	0.029
X-22A	15,980	449	0.028
XC-142A	37,500	1,266	0.034

*STOL-type aircraft

TABLE 10
FLIGHT CONTROL SURFACE
ACTUATION SYSTEMS DATA

Aircraft	Flight Design Weight (lb)	Flight Control Weight* (lb)	Flight Control Weight* (% of Des Wt)
OV-1D	15,421	552	3.5
DHC-4	28,500	467	1.6
DHC-5	41,000	610	1.5
Breguet 941	46,000	1,056	2.3
F-28	50,000	1,009	2.0
C-123B	54,000	599	1.1
737-200	100,000	2,182	2.2
B-47B	125,000	2,047	1.6
C-130B	135,000	1,645	1.2
727-100	161,000	2,996	1.9
C-124C	185,000	1,493	0.8
720-022	203,000	2,199	1.1
C-133A	275,000	1,804	0.9
C-5A	728,000	6,543	0.9

*Reported flight control weight

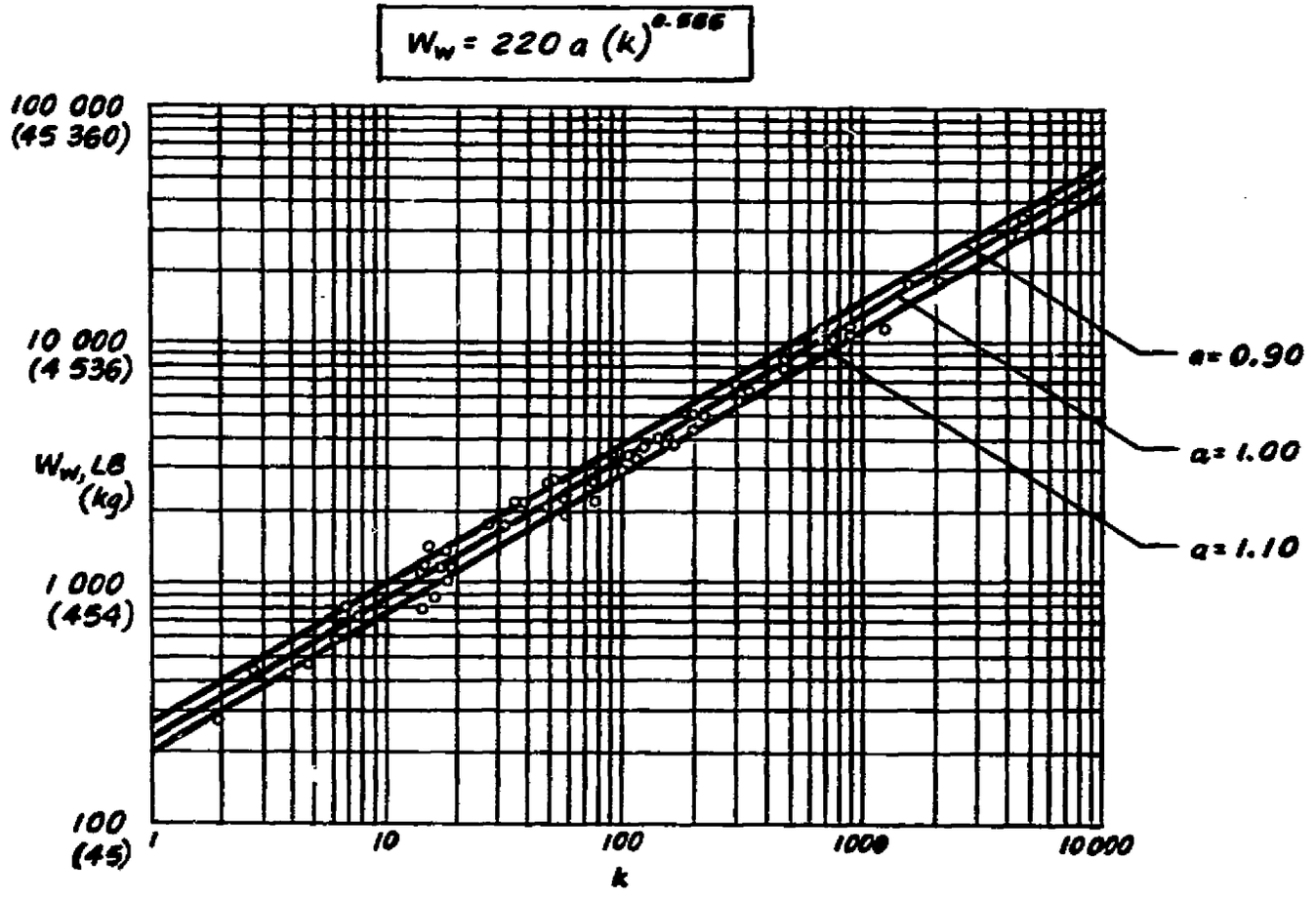


Figure 53. Wing Weight Trend Used in GASP.

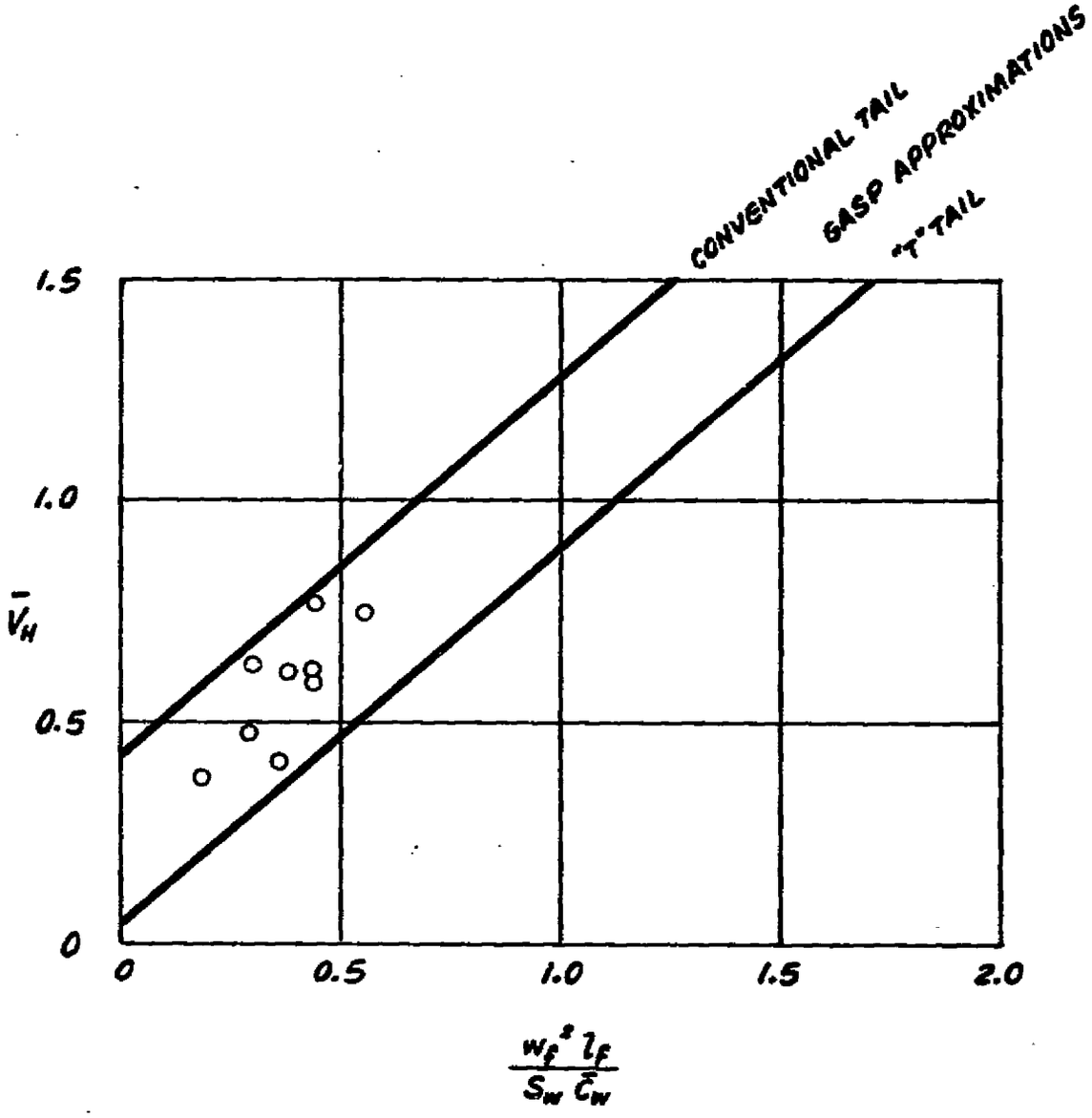


Figure 54. Correlation of Horizontal Tail Volume Coefficient with Fuselage-Wing Geometry Parameters.

5.3.2. Input Format And Ease of Use

After using the GASP extensively in this study, Cessna feels that the input format needs considerable work. As it now stands the program is cumbersome to use.

Of course, many of the difficulties Cessna has experienced in using the GASP will be eliminated when the program documentation is completed.

After using the program and reviewing the preliminary documentation, the following suggestions are made. (In the interest of brevity the GASP terms are not defined. The reader is assumed to have a copy of the program documentation).

1) The implications and limitations of each input must be carefully delineated.

a) Example: if in CONTROL, WG >12500 or NTYE = 7 then the manufacturing manhours are calculated based on a weight-speed product;otherwise;they are based on the empty weight.

b) Example: in PERFRM, TDELTX will not affect the engine sizing. TDELTO in ENGSZ must be used for that.

c) Example: in WGHT, ELINC is used to determine tail arms if and only if LCWING = 1.

d) Example: in FLAPS, VKTIN is used only to determine Reynolds number.

e) A cross reference between the inputs is needed so that if the user wishes to change, say speed, he knows which other inputs will also change.

2) Some numbers now input and not modified by the program need to be updated based on program results.

a) Example: TDELTO in ENGSZ should default to the value of TDELTX

b) Example: RWCRTX in CTAER should be updated, when the plane is being sized for a given range, to reflect the weight ratio from the previous range iteration.

c) Example: in FLAPS, VKTIN should be reset to the stalling speed and the $C_{L_{MAX}}$ recalculated until the two are in agreement.

3) In CONTROL subroutine, KWRITE must be explained in detail, it is too easy to miss needed output in one part of the program and in another wind up with excessive output. Also an option should be provided such that, when the range balance option is being used, a detailed takeoff time history can be obtained for the final sized airplane.

4) In SIZE subroutine

a) PAX-needs an explanation that this excludes the pilot.

b) WPLX-the interaction with KPLRG in WGHT must be carefully explained.

c) SAH-what is this referenced to? I.e. is the base of the vertical tail (SAH=0) measured from the fuselage centerline? Top of the fuselage?

d) VMLFSL-how is this obtained before the GASP is run? Some of the outputs of the GASP are needed before it can be calculated. Cannot this be done internally in the program?

5) In PERFRM subroutine

a) THEMAX-an explanation of how this is used is needed.

b) DELTT. The GASP presently calculates taxi fuel as DELTT times the idle power fuel consumption. The General Aviation Manufacturers Association

defines the fuel required for startup, taxi and takeoff as the fuel consumed during 5 minutes with all engines at takeoff power. The GASP should be modified to this latter definition.

6) In WGHT subroutine, KPLRG must be carefully explained. Illustrative examples of the effects on output would be helpful.

5.3.3 Miscellaneous Features Of The GASP

The GASP was run on Cessna's IBM 370/158 DOS. The following changes were required before the program would execute properly.

1) Converted the character @ to an apostrophe throughout the program, especially the assembler language input routine. (BCD to EBCDIC conversion).
2) Changed logical unit numbers 5 and 6 to 1 and 3 for read and write statements respectively to meet this installation's systems requirements.
3) All variables in common, initialized in data statements, were changed to be initialized without using the data statements. This is due to the fact that the IBM 370 does not allow a variable in labeled common to be initialized in a data statement unless it is in block data.
4) The subroutine names "MAPS" was changed to "MAPS2" to compensate for an unallowed similar common label name (MAPS) in subroutine maps. Some with "AEROUT".
5) To meet the input routine requirements, many variable names entered as arguments in the "CALL INPUT" statements less than 6 characters in length, had to be followed by a blank character.
6) Since IBM only provides for 7 digits accuracy for single precision, the whole program had to be double precisioned for 16 digit accuracy (minimum of 13 digits).

The program output, in general, is poor. The weight section summary, the drag summary and the dimensional data summaries are good. Otherwise, the output tends to be cluttered. It is difficult to find things; particularly when running the range balance option, the user may find difficulty in deciphering where to read some parts of the output. In many cases the output is not adequately labeled.

The input should be printed out in a neatly labeled block rather than spread throughout the output in the order it was read.

Naturally a program that does as much as GASP has a large output. The quantity of output, however, makes it difficult to locate errors, even obvious ones. If, for example, the input has resulted in an excessively large tail area being generated, this may escape the attention of the user. A set of tests that would warn the user that a certain output exceeds normal limits would be very useful.

Further, the output value of $C_{L_{MAX}}$ is an out of ground effect value. The V_S value is an in ground effect value. Both variables should be output for both conditions. The output should be clearly labeled as to which values are for in ground effect and which are for out.

The iteration routine, used in RGBAL to determine the required aircraft gross weight for a given range, is inefficient. Further, it sometimes fails to close to the solution when there is every indication that had the loop executed once more it would have succeeded.

The detail with which this design has been examined, within the short time allotted, is, of course, possible only with the aid of modern high speed computers. At present Cessna's design programs are adequate; but no one program yet exists to oversee the running of the others. This is still the function of the engineer. Thus, while the majority of the drudgery has been removed and the design process greatly speeded there is still room for significant improvement.

Therefore, once the deficiencies of the GASP, noted in this report, are corrected it will fill a real and pressing need. This is undoubtably true for the entire general aviation industry which is just now beginning to adopt the computer aided design techniques that have been pioneered by the large aircraft industry.

5.4 IDENTIFICATION OF DESIGN AND TECHNOLOGY REQUIREMENTS OF SINGLE TURBOFAN POWERED LIGHT AIRCRAFT

As can be seen from Section 5.2, the economics of the light turbofan powered trainer do not compare favorably with current piston-powered light aircraft such as the Cessna 150. Part of this is due to the higher fuel consumption, and consequent greater aircraft size, of the turbofan, and part is due to the higher cost of the engine. Before such an aircraft can be profitably produced and operated, the fuel consumption and the cost of the engine must be significantly reduced. The engine price used in this study was $25/lb SLS thrust. Even this number appears overly optimistic in comparison to today's turbine engines which cost approximately $50 to $60/lb SLST. To compete, the cost must be brought down to a level comparable to today's reciprocating engines. These cost approximately $5/lb SLS thrust. The reduction in fuel consumption and price are the primary technological advances needed to make turbofans competitive with reciprocating engines.

In fact, this study has failed to identify any other areas in which new technology and design would significantly improve the marketability of the light turbofan powered aircraft. The final design, in every area but the engine, proved to be conventional and capable of being constructed using today's technology.

6.0 REFERENCES

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7.0 APPENDIX I

7.1 DIRECT OPERATING COST EQUATIONS (REFER TO SECTION 3.1.2.1)

1) Engine Periodic Maintenance =

$$.529\left[\left(1 + 1.667*10^{-5}T\right)\left(\frac{R}{V_B} - .1\right) + 1.45\right]\frac{Ne\ L_R}{R}$$

$$+2.06*10^{-5}\left(\frac{R}{V_B} + .25\right)\frac{Ne\ Ce}{R}$$

Where:

T = Sea level static thrust/eng. (lb)
R = Range (N Mi)
V_B = Block speed (knots)
Ne = Number of engines/plane
L_R = Maintenance labor rate ($/hr)
Ce = Cost of engine (Retail-to customer)

2) Engine Overhaul =

$$.376\ Ce/TBO*V_B$$

Where:

TBO = Time between overhauls (hrs)

3) Airframe Maintenance =

$$(.00188\ \tilde{W} - .525)/V_B$$

Where:

$\tilde{W}$ = DEW - Engine, prop, and electrical systems (lbs)

4) Hull Insurance =

$$1.09P^{.623}/u\ V_B$$

Where:

P = Airplane price
u = Utilization rate (hrs/yr)

5) Liability Insurance =

$$(200 + 25N_p)/u\ V_B$$

Where:

N_p = Number of places

6) Fuel Cost =

$F_B * P_G / SWF * R$

Where:

F_B = Fuel burned (lbs)
P_G = Price per gallon of fuel ($/gal)
SWF = Specific weight of fuel (lb/gal)

7) Oil Cost =

$OC * P_O / V_B$

Where:

OC = Oil consumption (quarts/hr)
P_O = Price of oil ($/quart)

8) Depreciation =

$$\frac{C_{AF} + Ce + C_{AVI} + C_{BATT}}{7.5 \text{ u } V_B}$$

Where:

C_{AF} = Cost of airframe
C_{AVI} = Cost of Avionics
C_{BATT} = Cost of battery
7.5 = Years for depreciation (to zero residual)

8.0 ERRATA

8.1 ENGINE PRICE IN GASP ANALYSIS

After this study was completed, a difference between the Cessna and GASP costing estimate was discovered. The Cessna method assumed that the cost of the engine to the customer was $25/lb SLST. The input to GASP was such that the cost of the engine to the manufacturer was $25/lb SLST. The manufacturer and dealer markups used by the GASP raised the customer cost to $46.52/lb SLST.

If the GASP is modified so that the engine cost agrees with the Cessna estimate then the customer price drops from $37603 to $24750 and the DOC is reduced from $ .413/N Mi to $ .358/N Mi.

Since this change will also effect the slope of the DOC lines on the final GASP sizing plot (Fig. 49) the minimum DOC plane may fall at a different combination of wing size and thrust. This will not, however, effect the fact that the GASP is sizing the plane much larger than the Cessna methods nor will it alter the difference in slope of the TOFL line that is shown in Fig. 40 and 49 and discussed in Section 5.2, pg. 105.

8.2 TOFL SIZING REQUIREMENT

Upon completion of the study it was found that Cessna's takeoff field length analysis, done in connection with the wing and engine sizing (Sections 4.2 and 4.3), is not consistent with the specified design condition; i.e., 1700 ft. at S.L. 90°F. While the analysis accounted for the effect of temperature on engine thrust it did not properly consider the effect of temperature on air density.

This is equivalent to sizing to an increased takeoff field length of approximately 3.5%; i.e., the Cessna baseline was sized to a TOFL of 1760 ft. rather than the 1700 ft. specified.

8.3 EVALUATION OF TOFL FOR GARRETT DESIGN

In Section 4.1.1.4, Cessna's evaluation of the takeoff field length estimate for the Garrett design did not account for the effect of flaps. The Cessna estimate was made assuming a flaps up takeoff while the GASP analysis assumed that the flaps were set at 10°.